Ark of Inquiry: Inquiry Activities for Youth over Europe

Deliverable D4.1

Web-based supportive materials/guidance

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Legal Notices

Summary

This deliverable concerns the development of web-based/supportive materials that provide a basis for guidance to teachers, teacher educators/researchers, scientists and parents for enacting their own role in pupil inquiry implementations. Overall, the idea is to create a mechanism that can ensure the sustainability of the Ark of Inquiry both during and after the project.

The deliverable begins with an introduction to illustrate the need for the development of supportive materials for each stakeholder (teachers, teacher educators/researchers, scientists, and parents), and the rationale behind selecting each particular stakeholder is explained and documented. Next, the purpose of the deliverable is explicated and an overview of the structure of the sections that follow is provided. In the subsequent section, the methodology used for the development of the web-based materials is described and the emerged themes that fostered the development of the materials for each stakeholder are presented (see Table 1 for further details). The next section concerns the presentation of the web-based materials for each stakeholder. Each type of the web-based materials begins with an introduction that entails relevant theoretical considerations to document the need for the development of the web-based materials and is followed by the purpose and the methodology employed for the development of the web-based materials. The deliverable ends with an elaboration on how the web-based materials are informed by and connected with the work packages of the project in order to highlight the coherence and consistency among the work undertaken within the context of the rest of the work packages, and some conclusions derived from the content of the web-based materials and the procedure followed are also presented.

All the materials are provided in the Appendices of this deliverable, as well as on the website of the project:

Teachers: http://www.arkofinquiry.eu/teachers

Teacher Educators/Researchers: http://www.arkofinquiry.eu/teacher-educators

Scientists: http://www.arkofinquiry.eu/research

Parents: http://www.arkofinquiry.eu/parents

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1. Introduction

Inquiry, which refers to “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (National Research Council, 1996, p. 23), is at the core of the Ark of Inquiry project. Numerous research reports (e.g., Abd-El-Khalick et al., 2004; Bartos & Lederman, 2014; Capps, Crawford, & Constas, 2012; NRC, 2012) have indicated that learners can similarly benefit from this scientific approach through their engagement in learning activities centred on inquiry, and the resulting outcome is the development of inquiry learning. Inquiry learning has been defined in the current project as ‘an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding’ (NRC, 2000, p. 2) and more specifically as a process of discovering new relations, with an approach where the learner formulates hypotheses and then tests them by conducting experiments and/or making observations (see Pedaste, Mäeots, Leijen, Sarapuu, 2012). The main aim of inquiry learning is the improvement of transferable skills needed for making discoveries rather than simply discovering new relationships (Mäeots, Pedaste, & Sarapuu, 2009).

Besides fostering pupils’ engagement with inquiry, the Ark of Inquiry project seeks to create a new generation of pupils who are able to benefit from the implementation of Responsible Research and Innovation practices in their everyday life. Responsible Research and Innovation (RRI) is defined as a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society) (Towards Responsible Research..., 2011). Such approaches can bridge the gap between the scientific community and society.

The key for a successful design and implementation of science instructional settings through which learners will be scaffolded in developing inquiry and RRI skills is the *teacher*, given that teachers are considered to be the “linchpin” in any effort to change science education across nations (National Research Council, 2012). This assertion signals two interconnected requirements for teachers: teachers should develop sufficient knowledge of new curriculum contents and methods, and at the same time they should be competent enough to teach them (Van der Valk & de Jong, 2009). We cannot continue to expect teachers to carry out inquiry-based curricula without figuring out how to support them in understanding the philosophies underlying these curricula (Crawford, 1999; Crawford, 2000). Hence, significant emphasis should be placed on enhancing their professional development. This, in turn, “puts new demands on the professional development of science teachers” (Van der Valk & de Jong, 2009, p. 829), and, therefore, *teacher educators* and *researchers* need to carefully design learning experiences for teachers to facilitate their professional development regarding inquiry. Consequently, teachers and teacher educators/researchers are considered two of the main stakeholders/supporters that will help reach the project's objectives.

Besides helping learners acquire scientific inquiry skills and general inquiry knowledge in the context of science, the Ark of Inquiry project also aims to encourage learners to experience a number of inquiry activities that are specific to the work of scientists and realise how science works and how scientists work. Therefore, *scientists* (especially those in STEM and education) are considered as a third category of stakeholders that are expected to impact both in the success of the project and the sustainability of the system developed in the project. Specifically, scientists are expected to contribute in supporting the network for teachers in understanding and using the Ark of Inquiry material on RRI, so that they can effectively work together with the pupils. They can also share their habits of everyday work with teachers (e.g., during teacher training sessions) or pupils (e.g., during classroom visits or pupils' visits to scientists' labs). In doing so, they will need specific types of support in terms of how important constructs (e.g., inquiry, inquiry learning, RRI) and procedures (e.g., how to engage learners in inquiry activities, how their work can be adapted in designed inquiry instructional settings) are approached within the context of the Ark of Inquiry project.

Lastly, the fourth category of stakeholders that play an important role in supporting learners' systematic engagement with inquiry learning both inside and outside the school is *parents*. Evidence from research reports has shown that children do better in school, exhibit more self-confidence and express higher expectations for themselves if their parents support their learning and are actively involved in their education (AAAS, 2004; Moll et al., 1992). This stance is also in line with the very strong positive relationship found between school performance and conducive to learning in the home environment (Downey, 2002). Although their role is crucial in creating a home learning environment that will welcome and foster children's engagement with inquiry activities in a similar way they are organised in school, the majority of parents are not equipped with the necessary knowledge and skills to accomplish such an endeavour. Therefore, providing support to parents is also considered important in the context of the Ark of Inquiry project.

2. Purpose and outline of D4.1

The purpose of D4.1 concerns providing guidance to teachers, teacher educators/researchers, scientists and parents on how to support pupil engagement in inquiry challenges. This guidance is in accordance with the role that each of the aforementioned supporters is expected to play in pupils' inquiry endeavours. Overall, the idea is to create a mechanism that can ensure the sustainability of the Ark of Inquiry both during and after the project. Also, given the notion that all aforementioned stakeholders/supporters (teachers, teacher educators/researchers, scientists and parents) are considered life-long learners who continuously seek new sources of knowledge and guidance for (i) further improving their current understanding of how inquiry and RRI can be shaped within their everyday practices, (ii) fine-tuning their inquiry-based teaching skills, (iii) bringing innovative inquiry-related ideas into their teaching practice, (iv) rethinking the design principles of the existing curricula that are built on the grounds of inquiry, and (v) staying abreast of the latest theories of inquiry approach (teaching and learning), the showcase of the web-based materials that have been developed as a result of the present deliverable is considered of pivotal importance.

D4.1 is organised in four sections. First, the methodology followed for the development of the web-based materials is described and the emerged themes that fostered the development of the materials for each stakeholder are presented (see Table 1 for further details). The second section concerns the presentation of the web-based materials for each stakeholder. Each type of the developed web-based materials begins with an introduction that entails relevant theoretical considerations to document the need for the development of the web-based materials and is followed by the purpose and the methodology used for the development of the web-based materials. The actual web-based materials are provided in the Appendix due to their length. Third, an elaboration on how the web-based materials are informed by and connected with the work packages of the project is provided in order to highlight the coherence and consistency among the work undertaken within the context of the rest of the work packages. The deliverable ends with some conclusions derived from the content of the web-based materials and the procedure followed.

3. Methodology for the development of the web-based materials

We developed specific web-based supportive materials that are currently available for access through the project's website main menu (Web-based materials: https://sisu.ut.ee/ark/node/5585) or through each type of supporter's page:

Teachers: http://www.arkofinquiry.eu/teachers,

Teacher Educators/Researchers: http://www.arkofinquiry.eu/teacher-educators,

Scientists: http://www.arkofinquiry.eu/research,

Parents: http://www.arkofinquiry.eu/parents.

These materials (or guidance) focus on introducing to each type of supporter their role in the Ark of Inquiry activities, in conjunction with providing specific guidance and information about several aspects of inquiry approach (teaching and learning). The development of the web-based materials was established through the following procedure:

1. The coordinators of WP4 suggested possible themes for the development of the web-based materials for each of the aforementioned stakeholders. The suggested themes were sent via electronic communication to all partners who were involved in WP4 and were also presented and explained during a Skype meeting. The partners were asked to reflect on the suggested themes and propose revisions or additions to the list of the themes.
2. Based on the ideas exchanged and the suggestions of the partners involved in D4.1, the list of possible themes for the development of the web-based materials was refined, and the final list was as follows (Table 1):

Table 1: Summary of the themes of the web-based materials that have been developed for each stakeholder

Web-based materials for…	Theme
…teachers	Definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry
	Phases of inquiry that learners go through during their engagement in inquiry activities
	How does an inquiry-based curriculum look like?
	Skills and practices involved during inquiry learning
	Several types of support and means to provide constructive feedback to pupils in the Ark of Inquiry activities

…teacher educators/researchers	How to support teachers in understanding and using the Ark of Inquiry materials both during teacher training and implementation?
	How can successful teacher preparation practices in inquiry learning reported in the literature inform the design of teacher professional development courses in the context of the Ark of Inquiry project?
	How/when/why to prompt teachers to reflect on their evolved understanding of inquiry learning and inquiry approach (instruction)?
	A showcase of instruments to capture teachers' initial, evolving and final understanding of various underpinnings that relate to inquiry learning and teaching science as inquiry
…scientists	Definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry
	Phases of inquiry that learners go through during their engagement of inquiry activities
	Skills and practices that are involved during inquiry learning
…parents	Background information about the outline of the Ark of Inquiry project
	Explaining what scientific inquiry is through an example of an inquiry activity
	How to support your children at home?

3. Next, the coordinators of D4.1 asked each partner to express interest in choosing the theme(s) that they would like to develop based on their professional expertise and prior work with topics similar to the themes of the web-based materials. The coordinators monitored the distribution of the themes to the interested partners and also suggested a mechanism for their development and refinement. This mechanism entailed the following steps:
    a. The partner who was in charge of developing a specific theme in the form of web-based materials was given a month for preparing and sending the first draft of the materials to the D4.1 coordinators.
    b. Three other partners, who were suggested by the D4.1 coordinators and not involved in the development of specific web-based materials, were asked to serve as internal reviewers to the first draft of the materials. The reviewers were given specific guidelines on how to approach the review of the web-based materials (e.g., check if the materials are in line with the theme they were connected with, check the consistency of the content of the materials

with the terminology agreed within the Ark of Inquiry consortium as well as with the DoW from the project proposal, check the structure, format and language used for developing the materials, etc.) and were asked to prepare their constructive feedback within a suggested time frame (they were provided with enough time to go through the submitted materials and prepare their review).

c. After receiving all three reviews for each individual theme of the web-based materials, the coordinators reviewed the submitted feedback in terms of its consistency with the guidelines provided to the reviewers and sent the reviews to the author of the web-based materials. The authors were asked to study the proposed review and make necessary revisions and improvements in their web-based materials based on the comments and suggestions of the reviewers. In the event of an unclear comment in the received review, the authors were asked to communicate directly with the partner who prepared the review and ask for clarifications.

d. The revised versions of the web-based materials were submitted back to the initial reviewers (second round of review) to check their consistency with the feedback provided, and the coordinators of D4.1 monitored the review process. In some cases, the submitted web-based materials were sent back to their authors for further improving specific parts of the content and structure of the materials.

4. Once all the web-based materials were finalised and sent back to the D4.1 coordinators, the coordinators asked each author of the materials to prepare a report on the methodology followed for their development. The guidelines for preparing the report were as follows:

    a. Introduction
        i. Make a brief intro into the theme of your web-based materials.
        ii. Provide necessary justification to explain why the web-based materials you have developed are important in terms of the stakeholders that are intended to receive them (teachers, educators, scientists, parents).
        iii. Use bibliographical references to support your claims and arguments.
    b. Purpose
        iv. Explain the rationale behind the creation of the web-based materials.
    c. Methodology
        v. Describe the methodology/process followed for developing your materials, e.g., “What resources have you looked into?”
    d. Presentation of the web-based materials
        vi. Make a summary of the structure and content of your final product (web-based materials).
        vii. Provide any background information to the reader to facilitate the reading of your materials.
    e. Appendix
        viii. The web-based materials

4. Presentation of the web-based materials

The web-based materials that were developed for the purposes of the D4.1 are provided below in four consecutive sections according to the four different types of supporters/stakeholders. The presentation starts with the web-based materials for teachers, followed by the web-based materials for teacher educators/researchers, web-based materials for scientists, and web-based materials for parents, respectively. For each theme of the web-based materials, a short introductory note that illustrates the connection of the materials with prior research reports appears first, followed by the purpose of the web-based materials, the methodology used for developing the web-based materials, and a brief description of the web-based materials in terms of their structure and organisation. The actual web-based materials are provided in the Appendix along with the corresponding web links to the Ark of Inquiry website.

4.1 Web-based materials for teachers

The introductory note that appears on the main page of the web-based materials for teachers can be found in Appendix 8.1.

4.1.1 Definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry

Introduction. It has been documented for years now that European pupils' interest in science, mathematics and technology has been declining along with the increase in grade levels. Another alarming issue for Europe is the recruitment of pupils for science and technology related careers. According to the results of the ROSE Project, extremely few girls wish to become scientists, and even for boys, the percentage is low. Specifically, in Europe, around 50% of boys provided a positive response to the question "I would like to get a job in technology", but very few girls indicated that they would like to pursue such a career option (Sjoberg & Schreiner, 2010). These kinds of results from project reports highlight the urgent need for more effective action on the teaching and learning of science in schools (Cavas, 2012).

The science education community mostly agrees that pedagogical practices based on the inquiry approach are more effective for the teaching and learning of science. However, the reality of classroom practice is that in the majority of European countries, these methods are only being implemented by relatively few teachers (Rocard et al., 2007). The report continues to explain the advantages of inquiry based science education (IBSE), and the recommendations clearly promote the use of IBSE for the teaching and learning of science in Europe.

In addition to IBSE, the European Commission has developed a new concept responding to the aspirations and ambitions of European citizens: a framework for Responsible Research and Innovation (RRI). In the report "Europe's ability to respond to societal challenges", RRI pertains to the attempts of all societal actors working together during the whole research and innovation process in order to better align both the process and its outcomes with the values, needs and expectations of European society. RRI is an ambitious challenge for the creation of a Research and Innovation policy driven by the needs of society and engaging all societal actors via inclusive participatory approaches (Quinn, 2012).

Purpose of this task. The purpose of the development of these web-based materials is to provide information to teachers about the key features of inquiry learning and Responsible Research and Innovation (RRI).

Methodology. In order to prepare the web-based materials, we reviewed the related literature on inquiry and the inquiry approach (learning and teaching) with an explicit focus on the meaning of inquiry, inquiry learning, and inquiry based science education. In addition to the articles published in the science education journals, the key reports published by the European Commission have also been reviewed.

Description of the web-based materials developed. The web-based materials that have been developed for teachers entail the definition and explication of inquiry and Responsible Research and Innovation (see Appendix 8.2)

4.1.2 Phases of inquiry that learners go through during their engagement in inquiry activities

Introduction. The quality of science education, which affects the future of countries, has been among the highest priorities internationally (Science with and for Society, 2015). There is a clear consensus that rich science education environments provide the base for educating individuals to be scientifically literate people (Abd-El-Khalick et al. 2004; Minner et al. 2010). According to the National Research Council in USA (NRC, 2000), scientific inquiry and teaching practices are defined as a set of interrelated processes by which learners pose questions about the natural world and investigate phenomena; in doing so, learners acquire knowledge and develop a meaningful understanding of concepts, principles, models and theories. Inquiry is a critical component of a science programme at all grade levels and in every domain of science, and designers of curricula and programmes should verify that the approach to content as well as teaching and assessment strategies reflects the acquisition of scientific understanding through inquiry. Pupils will then learn science in a way that reflects how science actually works (NRC, 2000, p. 214).

Science educators have suggested that many benefits accrue from engaging learners in different types of inquiry activities. Many studies indicate that the use of the innovative and authentic practical inquiry approach not only supports pupils' learning of high-level investigative skills but also enhances and develops pupils' meaningful learning, conceptual understanding, understanding of the nature of science, critical thinking and communication skills (Kask and Rannikmäe, 2009; Laius et al., 2008; Trumbull, et al., 2005). Teachers play an important role in conceptualising and organising the type and suitability of inquiry activities. Many studies have revealed that such experiences can have a powerful influence on pupils' understanding of science and their interest in science teaching (Boardman et al., 1999; Dana et al., 2000; Smith & Anderson, 1999; Zembal-Saul & Oliver, 1998; Blumenfeld et al., 2006; Hofstein et al., 2005).

Purpose of this task. The purpose of the development of these web-based materials is to provide information to teachers about the phases of inquiry.

Methodology. In order to prepare the web-based materials, a literature review has been done on the phases of inquiry. In addition to the articles published in science education journals, the key reports published by the European Commission have also been reviewed.

Description of the web-based materials developed. As a result of the analysis of the literature review, the Pedaste et al. (2015) inquiry learning framework was used as a main source for the development of the specific web-based materials (see Appendix 8.3).

4.1.3 How does an inquiry-based curriculum look like?

Introduction. There are widespread calls for adopting the inquiry approach as the preferred way of teaching pupils about science (AAAS, 1993; Chinn & Malhotra, 2002; NRC, 2012). Teachers' understanding of inquiry shapes their teaching and greatly influences how young learners perceive and understand inquiry. In spite of the critical role teachers have in the process of reforming science education, they are reported to have difficulties in teaching using the inquiry approach (Anderson, 2002; Barab & Luehmann, 2002). This failure might be attributed to the lack of existing frameworks that portray how inquiry can be approached in practice.

Pedaste and his colleagues (2015) aimed at contributing to bridging the gap through the review of a wide range of academic papers on the process of inquiry learning and the concepts that were used to describe this process. Their review revealed an inquiry learning framework comprising the following five major phases.

1. In the *Orientation phase* curiosity about a topic is stimulated, which should then result in a problem statement.
2. In the *Conceptualisation phase* research questions and/or hypotheses are stated.
3. In the *Investigation phase* empirical data is gathered and processed to resolve the research questions or hypotheses.
4. In the *Conclusion phase* research findings from the inquiry are reported and justified by the results of the investigation.
5. In the *Discussion phase* partial or completed outcomes of the inquiry as well as reflective processes are communicated to regulate the learning process. This phase is unique because of its constant connection to all the other inquiry phases. It is also particularly important because it teaches pupils the discursive nature of science.

In the context of the Ark of Inquiry project, the aforementioned phases are intended to serve as a cornerstone of the selection of criteria for the inquiry activities in the Ark of Inquiry project. Using the phases as a reference for assessing the activities will ensure that, apart from being productive in terms of learning outcomes, pupils get a good and comprehensive learning experience in the process that a) resembles scientific inquiry, b) helps to improve their inquiry skills and proficiency (i.e. the ability to generate and evaluate scientific evidence and explanations), and c) promotes their understanding of the process of conducting science in a better and more responsible manner.

Purpose of this task. The purpose of the development of the present web-based materials is to present a curriculum that was designed on the grounds of the Pedaste et al. (2015) inquiry learning framework to illustrate the type of activities that each phase/sub-phase of the framework entails.

Methodology. We reviewed the activities proposed by the project partners as a requirement for WP2 (collection of activities that are built around inquiry). We examined these activities using the criteria proposed by the coordinators of WP2 for selecting exemplary activities that are grounded on the premises of inquiry learning. Although the majority of the activities were designed around the inquiry learning framework, very few were found to meet the major criterion of entailing all phases of the Pedaste et al. (2015) inquiry learning framework. The one that was chosen to be presented here was found to be consistent with the framework and was proposed by partners from the University of Cyprus.

Description of the web-based materials developed. A description of a curriculum that was designed by the University of Cyprus group, which pertains to the topic "boiling and peeling eggs", is presented. The curriculum materials are grounded on the inquiry learning framework suggested by Pedaste et al. (2015). Learners engage in multiple inquiry cycles through the curriculum. They discuss the progress of their work with the course instructors during "check-out points" placed in specific points in the curriculum. During these check-out points, the instructors aim at engaging learners in semi-socratic dialogues, instead of merely answering questions or providing the correct answers to the activities of the curriculum. We extensively describe what learners (working in groups of 4) do in each phase of the inquiry cycle in order to highlight how the Pedaste et al. (2015) inquiry learning framework can be used to inform the design of an inquiry-based curriculum (see Appendix 8.4).

4.1.4 Skills and practices involved during inquiry learning

Introduction. Reform documents in science education have underlined the increasing importance of preparing effective teachers, who will play a key role in guiding pupils through cognitive activities centred on *inquiry* (NRC). To do this well, teachers should have at least a basic understanding of science subject matters, the nature of scientific inquiry and how to create an inquiry learning environment (Capps, Crawford & Constas, 2012.) Part of knowing the nature of scientific inquiry is knowing about the phases of inquiry and the skills and practices involved. When using the Ark of Inquiry in teaching pupils about inquiry it is necessary to know which skills and practices are involved so teachers can see, stimulate and evaluate those skills and practices during inquiry activities in their classroom. Although most people agree on inquiry being a cyclic process consisting of different inquiry phases, models of inquiry and inquiry learning might differ in the phases included and their names. Pedaste et al. (2015), in an attempt to solve this problem, compared and analysed 32 articles describing inquiry phases resulting in five inquiry phases that are distinctive for all inquiry cycles. These five inquiry phases involve different skills and practices for pupils to learn and do. (See Table 1).

Purpose of this task. The purpose of these web-based materials is to provide teachers with descriptions and examples of skills and practices involved in the five phases of inquiry. Teachers will be able to understand the cycle of inquiry and/or relate other models of inquiry they might have been using to the cyclic model presented here.

Methodology. Two sources were used for these web-based materials: (1) the review of Pedaste et al. (2015) explaining the five general phases of inquiry, and (2) the Ark of Inquiry deliverables D1.1: Description of inquiry approach that fosters societal responsibility, and D1.2: Instruments for evaluating inquiry experiences, skills and societal responsibility. The latter explains the evaluation system used in the Ark of Inquiry that assesses pupils' progress and levels of inquiry.

Description of the web-based materials developed. The web-based materials are organised according to the five phases of inquiry. Each phase is described along the skills that are part of it. After a short description of the phase and skills involved, a worked-out example illustrates the phase and skills in the classroom practice. The web-based materials are concluded with a table in which the five phases, skills and short examples are summarised (see Table 1) (see Appendix 8.5 for the actual web-based materials).

4.1.5 Several types of support and means to provide constructive feedback to pupils in the Ark of Inquiry activities

Introduction. It has been documented for years that learners can attain a deeper understanding of the concepts and processes of science if they are given opportunities to actively participate in inquiry activities. At the same time, evidence from the literature indicates that because inquiry is a rather demanding cognitive activity that increases pupils' cognitive load, pupils will be needing substantial support to "…become knowledgeable about content, skilled in using inquiry strategies, proficient at using technological tools, productive in collaborating with others, competent in exercising self-regulation, and motivated to sustain careful and thoughtful work over a period of time" (Krajcik, Blumenfeld, Marx, & Soloway, 2000, p. 1).

Purpose of this task. The purpose of this report is to provide information about ways to aid pupils via several types of support during their participation in inquiry activities as well as how teachers can provide constructive feedback on pupils' work in progress. The support and the feedback mechanisms will be presented along the four phases of the inquiry learning framework proposed by Pedaste et al. (2015).

Methodology. We reviewed the empirical research that relates to the support mechanisms and means of scaffolding during engaging leaners with inquiry activities (Harlen, 2012; Krajcik, Blumenfeld, Marx, & Soloway, 2000; White & Gunstone, 1992), and in conjunction with our prior teaching experience and expertise in the domain of inquiry, we sought to identify supports and scaffolds for each phase and sub-phase of the inquiry learning framework of Pedaste et al. (2015).

Description of the web-based materials developed. The web-based materials are organised in a table. On the left side of the table, the phases and sub-phases of the Pedaste et al. (2015) inquiry learning framework are presented and briefly explicated, whereas on the right side of the table and next to each phase/sub-phase the types of support, scaffolds, guidelines and useful tips that were identified are presented and explained (see Appendix 8.6).

4.2 Web-based materials for teacher educators/researchers

The introductory note that appears on the main page of the web-based materials for teachers can be found in Appendix 8.7.

4.2.1 How to support teachers in understanding and using the Ark of Inquiry materials both during teacher training and implementation?

Introduction. Teachers have a key role in improving inquiry learning in schools (NRC, 1996). Teacher educators and researchers could therefore help teachers to invest in inquiry learning in their schools by providing support. Capps, Crawford and Constas (2012) state that one of the key features of effective professional development on inquiry learning is to have extended support for teachers. This extended support is important because it offers teachers the opportunity to interact with others, ask questions and receive feedback on inquiry learning/teaching outside the training sessions aimed at professional development. In the Ark of Inquiry, teacher educators and researchers could provide this extended support during training and implementation in their networks of (science) teachers. These web-based materials therefore provide ideas and materials that teacher educators/researchers can use when giving extended support.

Purpose of this task. The purpose of these web-based materials is to provide teacher educators and researchers with ideas and materials to support teachers in using the Ark of Inquiry during training and implementation.

Methodology. For this purpose, the review of Capps et al. (2012) on effective professional development on inquiry was used as a general framework to organise the ideas and materials. In addition, the following deliverables of the Ark of Inquiry were used to provide the first content of these web-based materials:

- D1.1 Description of inquiry approach that fosters societal responsibility
- D1.2 Instruments for evaluating inquiry experiences, skills and societal responsibility
- D1.3 Description of the system of Inquiry awards that foster responsibility
- D1.4 Specification of support systems in Ark of Inquiry
- D2.1 Criteria for selection of Inquiry activities including societal and gender dimensions
- D2.2 Pedagogical inquiry scenarios for re-use of inquiry activities

The information from the deliverables was used within the framework of extended support, so that a first outline of questions and answers was modelled across extended support measures. The following main questions teachers might frequently have about the Ark of Inquiry were taken as a starting point:

1. How to use the Ark of Inquiry during my lessons?
2. How can I contribute to the Ark of Inquiry?
3. How does the award system of the Ark of Inquiry work?

The main questions consist of several sub-questions. The answers to the questions are compiled in ready-to-use tables that provide first insights into when and how to address which questions of the teachers during training and implementation.

Description of the web-based materials developed. First, a short summary of the extended support measures is given (Table 1), followed by three tables presenting ideas and information related to questions teachers might have when they start to use the Ark of Inquiry:

Table 2: How to use the Ark of Inquiry during my lessons?

Table 3: How can I contribute to the Ark of Inquiry?

Table 4: How does the award system of the Ark of Inquiry work?

For each main question and its sub-questions, necessary information and a suggestion for extended support measures are given (see Appendix 8.8).

4.2.2 How can successful teacher preparation practices in inquiry learning reported in the literature inform the design of teacher professional development courses in the context of the Ark of Inquiry project?

Introduction. Reform documents in science education have underlined the increasing importance of preparing effective teachers, who will play a key role in guiding pupils through cognitive activities centred on *inquiry*, including the following: pupil-generated questioning; designing and conducting scientific investigations; use of technology to enhance investigations and communications; formulating and revising scientific explanations and models using logic and evidence; recognising and analysing alternative explanations and models; and communicating and defending a scientific argument (NRC, 1996). Despite this persistent call, most teachers still do not routinely adopt the inquiry approach (instruction) within their practices due to a number of systemic and other barriers such as time, unfamiliarity with how science is practiced, inadequate preparation of how to teach science through inquiry, etc. Consequently, current research reports have stressed that the key to overcoming this gap is to invest in teachers' professional development at both pre- and in-service level. A critical challenge that emerges in response to this gap is to identify the key features that professional development programmes should entail in order to succeed in changing teachers' epistemic knowledge of the nature of scientific inquiry, helping teachers appreciate the impact of inquiry learning on pupils' scientific literacy and assisting them in understanding how to design inquiry-oriented instruction in their classrooms (Capps et al., 2012).

Purpose of this task. The purpose of this report is to provide information to teacher educators and researchers about the key features that were incorporated into the design and implementation of different professional development courses reported in the literature, in conjunction with teachers' learning outcomes that were revealed as a result of their participation in these courses. These, in turn, can be approached as examples of successful practices derived from the literature on teachers' professional development in inquiry learning.

Methodology. For this purpose, we reviewed the relevant literature by using specific keywords. In particular, we searched for studies concerning professional development courses for (i) teachers in general, (ii) science teachers in several domains, and (iii) science teachers in the context of the inquiry approach (teaching and learning) by using the following keywords: professional development, inquiry-based teaching, inquiry-based learning, teacher preparation, teacher training. Our initial search revealed 128 papers. After reading the abstracts of these papers we deemed 6 papers to be the most representative of our purpose. The criteria used for this selection included popularity of this work among scholars and its recency (whether it was relatively recent). The outcomes of our review were compiled in tables, in an attempt to make apparent to the reader the characteristics of effective professional development courses that can be taken into account in future design and implementation of related courses.

Description of the web-based materials developed. The presentation of these features begins with a summary of the characteristics of effective professional development programmes in the field of general education (e.g., Darling-Hammond & McLaughlin, 1995; Loucks-Horsley et al., 1998) and in science and mathematics education (e.g., Garet et al., 2001; Penuel et al., 2007) prepared by Capps et al., 2012 (see Table 1). Next, we present examples of models or theoretical frameworks that were used for the design of professional development courses, along with their outlines, as well as how these courses influenced a change in teachers' conceptual understanding, beliefs, practices, etc. (Table 3). Finally, in Table 3 we illustrate evidence to document how the critical features of effective inquiry suggested by Capps et al. (2012) were addressed in the design and implementation of a PD programme for the purposes of the Ark of Inquiry project (see Appendix 8.9).

4.2.3 How/when/why to prompt teachers to reflect on their evolved understanding of inquiry and inquiry approach?

Introduction. Teachers and educators in general develop practices of teaching which make them feel comfortable and confident. When they mature it is usually difficult to change, or they feel insecure adopting an innovative methodology such as inquiry approach. However, when asked in surveys, the majority of teachers express the willingness to adopt new methods and models of science teaching that have proven effective and that lead their pupils to better results in terms of concept and content understanding. A required condition is that they are thoroughly trained in practicing these new methods before applying them in their everyday classroom teaching.

In this context, dedicated workshops with a well-balanced mix of advanced, experienced and non-experienced teachers help them to practice by following examples, develop further and reflect on their best practices and understanding on various subjects such as what is an inquiry process, what is inquiry-based instruction and science teaching, what are the main advantages of this method, which are the common mistakes to avoid, etc. These workshops, often called "practice reflection workshops" in the literature, can be offered in parallel or within the framework of professional development programmes and on a regular basis so that more teachers can be involved. They can be grouped in terms of subject and content or in terms of level of difficulty and prerequisites. In general, three series of workshops are proposed, which follow the general training framework and approach of the "Ark of Inquiry" project, which, as already described in the other sections, involves the participants in three distinct modes, i.e. as learners, as thinkers and, finally, as reflective practitioners.

Purpose of this task. The purpose of the web-based materials that have been developed concerns providing insights to teacher educators into how, when, and why to prompt teachers participating in training seminars/workshops or extended professional development courses to reflect on their evolved understanding of inquiry, inquiry learning and inquiry approach (teaching).

Methodology. We reviewed the literature in the domain of teacher professional development and teacher training (both pre-service and in-service), seeking for evidence from research reports on how and when teachers who are enrolled in teacher training seminars/workshops or extended professional development courses should be asked to reflect on their evolved understanding of inquiry, inquiry learning and inquiry approach (teaching). Given that the teacher training courses that will be followed in the context of the Ark of Inquiry project will be split in three consecutive phases (e.g., teachers as learners, teachers as thinkers, and teachers as reflective practitioners), different prompts for reflection are suggested in each of the phases of teachers' training courses.

Description of the web-based materials developed. The web-based materials are divided in three sections according to the anticipated role that teachers should be given during their participation in the training courses. The presentation of the materials begins with prompts for reflection during the teachers as learners phase, followed by prompts for reflection during the teachers as thinkers phase, and finally prompts for reflection during the teachers as reflective practitioners phase (see Appendix 8.10).

4.2.4 A showcase of instruments to capture teachers' initial, evolving and final understanding of various underpinnings that relate to inquiry and teaching science as inquiry

Introduction. European educational policy sets inquiry based science education as a highly recommended way of achieving increased interest and literacy in STEM (Rocard, 2007). However, inquiry-based science learning and science education itself, too, implies different concepts in the European countries as well as different levels of implementation (Eurydice, 2010). Exchange of practices can advance this process (Schwarzenbacher et al, 2011), and awareness of the fact that inquiry learning has many definitions and that it is understood in various contexts as well as a healthy balance between theory and practice represents a priority when developing materials for use with teachers (Anderson, 2002).

The main goal of the Ark of Inquiry project is to help pupils develop inquiry expertise in science, and for achieving this goal, the Ark of Inquiry community needs to invest time and effort in teachers' professional development in learning and teaching science through inquiry. Hence, during the teacher training sessions or professional development courses that will be designed and implemented within the project, teacher educators and researchers need to be equipped with several tools that they could use for assessing participating teachers' understanding, skills, beliefs, (tacit or explicit) knowledge of the inquiry approach and framework and teaching science as inquiry. There are several solutions, but as Ark of Inquiry proposes approaching teachers as reflective practitioners, some existing reflective tools would be worth piloting with.

Therefore, in this report we offer a diversity of tools to be used for various purposes and with different aims in order to better serve the needs of teacher educators in the Ark of Inquiry network.

Purpose of this task. The purpose of this report is to provide a collection of various web-based materials, which were described in the literature or developed in various European projects related to STEM teaching and learning. We suggest that teacher trainers or teachers choose and adapt the materials best fit for their purpose based on the description of the specific tool and the related references. These materials provide a brief overview of the rationale and give ideas on how and when to use the tool.

Ark of Inquiry is an international project and, therefore, the tools will be used by a very diverse community of supporters, educators and teachers regarding the educational background (level of degrees), focus of teacher training (science or pedagogical content knowledge), and the framework of continuous professional development (Eurydice, 2010). Moreover, as Ark of Inquiry is meant for a pupil population of a wide age range (from 7 to 18), their teachers are likely to have received different trainings and have unalike knowledge. In some countries (in most European countries this is typical of grades 1–4), science is taught as a complex subject, integrating natural sciences even with other disciplines. There are differences between countries regarding disciplinary approaches (when and how science is separated into subjects), whether science learning is compulsory throughout the public education system and how science is referred to in curricula (as subjects, competences and/or cultural domains). In some countries, there are regular examinations or assessment tests in science subjects; in others, these tests are optional. Science teacher educators differ similarly. This explains why Ark of Inquiry intends to offer a wide range of tools.

Diversity should also be reflected on from the epistemological aspects of the assessment tools: the framework should be kept as wide (yet rigorous) as possible; without much elaborating on differences, parallels to similar models should be accentuated. We also kept in mind the requirements of the online working environment.

These online tools are to be used during the pilot phase of teacher trainings and the initial use of the platform, but then (after possible amelioration) they should be made available to the public. Therefore, some meta-analysis on their efficacy, accessibility (in the sense of legibility, inclusiveness and language) and suitability is necessary.

Methodology. For this purpose, after a literature review, we examined the tools suggested as well as good practices within the Ark of inquiry network. As the tools would be used by a diverse group of experts and practitioners in diverse environments, they should be clear, non-political, inclusive and as simple as possible. We have to be clear especially about the assessment tools that are meant to support and assess teachers' understanding of inquiry. Theory and practice should be balanced in a sophisticated way. Anderson (2002) puts it explicitly as follows:

> *"Research indicates that teachers focus on what works in terms of student involvement or classroom management, rather than on melding theory and practice (Blumenfeld, et al., 1994.) Teachers' understanding takes "the form of practical, not theoretical or propositional, knowledge" (Marx, et al., 1994, p. 517). Teachers anchor their understanding in classroom events and base it on stories and narratives more*

than on theories and propositional knowledge (Krajcik, et al., 1994). Teachers' view of teaching is "dominated by tasks and activities rather than conceptual structures and scientific reasoning" (Duschl & Gitomer, 1997, p. 65).

In other words, theory, beliefs, values and understandings are of critical importance in the process of teachers acquiring an inquiry approach to teaching, but one should not expect to address them in isolation from a practical context or expect that they will be addressed directly as mental constructs. It is a good example of the old shibboleth that the shortest distance between two points is not a straight line."

As also presented in D.1.1., ***inquiry based science education*** (and the inquiry approach (teaching and learning)) have several interpretations based on a diversity of understanding in the literature. Keeping in mind the diversity in the epistemological and practical understanding of inquiry based science learning, the Ark of Inquiry community works with the following inquiry framework:

"Inquiry learning has been defined in the current project in general as 'an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding' (de Jong 2006) and more specifically as a process of discovering new relations, with an approach where the learner formulates hypotheses and then tests them by conducting experiments and/or making observations (see Pedaste, Mäeots, Leijen, Sarapuu 2012)."

In order to cluster and describe steps during the ***inquiry learning journey***, Ark of Inquiry uses a 5-step model of learning cycles consisting of the following inquiry phases:

1. Orientation,
2. Conceptualisation,
3. Investigation,
4. Conclusion, and
5. Discussion.

The existing epistemological diversity in the inquiry approach (teaching-learning) and research represents a source for reflection, where the importance of thinking about epistemologies in the contexts of 'communities of practice' (Wenger, 1998) may be fruitful for practitioners:

"My claim here is that "alternative epistemologies" themselves admit of critical evaluation. As noted above, such evaluation will itself be conducted in terms of relevant criteria, such criteria being the property not of any given epistemology but rather of an overarching epistemological and philosophical perspective (or "metaperspective") that is neutral with respect to them all.

The more communication and understanding we can get across diverse communities of research practice, the better. Insofar as the motivation for enhancing epistemological diversity in the education research community is this pragmatic one, it is difficult to see any reason for rejecting it, other than equally pragmatic considerations, e.g., the multiplicity of extant epistemological perspectives and the shortage of time in a typical graduate student's schedule for mastering both the epistemologies of multiple communities of research practice and the philosophical knowledge and skills required to evaluate them. […]

To say this is not to call for the silencing of alternative voices or alternative approaches to research. On the contrary, openness to new voices and approaches should be both welcomed and encouraged by education researchers and incorporated into the education of future researchers. But conflating epistemological pluralism with a problematic relativism or scepticism can only hamper the important project of rethinking the graduate education of future education researchers. Keeping these distinct calls for epistemological diversity clear is a key step in the process of rethinking and ultimately enhancing the graduate education of current and future students of education research."(Siegel, 2006)

Description of the web-based materials developed. In this report we present tools organised around types such as online questionnaires, assessment tools and interview protocols. With each tool, we first summarise the characteristics and the rationale of the tool and then give a link to the paper describing the tool or (where the author agreed) the tool itself (see Appendix 8.11).

4.3 Web-based materials for scientists

4.3.1 Definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry

Introduction. It has been documented for years now that European pupils' interest in science, mathematics and technology has been declining along with the increase in grade levels. Another alarming issue for Europe is the recruitment of pupils for science and technology related careers. According to the results of the ROSE Project, extremely few girls wish to become scientists, and even for boys, the percentage is low. Specifically, in Europe, around 50% of boys provided a positive response to the question "I would like to get a job in technology", but very few girls indicated that they would like to pursue such a career option (Sjoberg & Schreiner, 2010). These kinds of results from project reports highlight the urgent need for more effective action on the teaching and learning of science in schools (Cavas, 2012).

According to a report published by the European Commission, the science education community mostly agrees that pedagogical practices based on the inquiry approach are more effective for the teaching and learning of science. However, the reality of classroom practice is that in the majority of European countries, these methods are only being implemented by relatively few teachers (Rocard et al, 2007). The report continues to explain the advantages of inquiry based science education (IBSE), and the recommendations clearly promote the use of IBSE for the teaching and learning of science in Europe.

In addition to IBSE, the European Commission developed a new concept responding to the aspirations and ambitions of European citizens: a framework for Responsible Research and Innovation (RRI). In the report "Europe's ability to respond to societal challenges" RRI pertains to the attempts of all societal actors working together during the whole research and innovation process in order to better align both the process and its outcomes with the values, needs and expectations of European society. RRI is an ambitious challenge for the creation of a Research and Innovation policy driven by the needs of society and engaging all societal actors via inclusive participatory approaches (Quinn, 2012).

Purpose of this task. The purpose of the development of these web-based materials is to provide information to scientists about the key features of inquiry learning and Responsible Research and Innovation (RRI).

Methodology. In order to prepare the web-based materials, we reviewed the related literature on inquiry and inquiry approach (learning and teaching) with an explicit focus on the meaning of inquiry, inquiry learning, and inquiry based science education. In addition to the articles published in the science education journals, the key reports published by the European Commission have also been reviewed.

Description of the web-based materials developed. The web-based materials that have been developed for scientists entail the definition and explication of inquiry and Responsible Research and Innovation (see Appendix 8.12)

4.3.2 Phases of inquiry that learners go through during their engagement in inquiry activities

Introduction. The quality of science education, which affects the future of countries, has been one of the highest priorities internationally (Science with and for Society, 2015). There is a clear consensus that rich science education environments provide the base for educating individuals to be scientifically literate people (Abd-El-Khalick et al., 2004; Minner et al., 2010). According to the National Research Council in USA (NRC, 2000), scientific inquiry and teaching practices are defined as a set of interrelated processes by which pupils pose questions about the natural world and investigate phenomena; in doing so, pupils acquire knowledge and develop a meaningful understanding of concepts, principles, models and theories. Inquiry is a critical component of a science programme at all grade levels and in every domain of science, and designers of curricula and programmes should verify that the approach to content as well as teaching and assessment strategies reflects the acquisition of scientific understanding through inquiry. Pupils will then learn science in a way that reflects how science actually works (NRC, 2000, p. 214).

Science educators have suggested that many benefits accrue from engaging pupils in different types of inquiry activities. Many studies indicate that the use of the innovative and authentic practical inquiry approach not only supports pupils' learning of high-level investigative skills but also enhances and develops pupils' meaningful learning, conceptual understanding, understanding of the nature of science, critical thinking and communication skills (Kask and Rannikmäe, 2009; Laius et al., 2008; Trumbull, et al., 2005). Teachers play an important role in conceptualising and organising the type and suitability of practical activities in science education. Many studies have revealed that such experiences can have a powerful influence on pupils' understanding of science and their interest in science teaching (Boardman et al. 1999, Dana et al. 2000, Smith and Anderson 1999, Zembal-Saul and Oliver 1998 Blumenfeld et al, 2006; Hofstein et al, 2005).

Purpose of this task. The purpose of the development of these web-based materials is to provide information to scientists about the phases of inquiry.

Methodology. In order to prepare the web-based materials, a literature review has been done on the phases of inquiry. In addition to the articles published in science education journals, the key reports published by the European Commission have also been reviewed.

Description of the web-based materials developed. As a result of the analysis of the literature review, the Pedaste et al. (2015) inquiry learning framework was used as a main source for the development of the specific web-based materials (see Appendix 8.13).

4.3.3 Skills and practices that are involved during inquiry learning

Introduction. Although most scientists agree on inquiry being a cyclic process in which pupils go through different inquiry phases, there is still a lot of variation in what these phases might be and how they are named. Scientists can move easily from one model of inquiry to the next because they are experienced and can see their overlap. For teachers, however, looking at different models of inquiry may be a burdening task. What they need is one general model that encompasses other variations as well, so that they can stick to the general model when working with their pupils on inquiry activities. Pedaste et al. (2015) tried to solve this problem by comparing and analysing 32 articles describing inquiry phases, resulting in five general inquiry phases that can be recognised in all (many) other models of inquiry. These five inquiry phases involve different skills and practices for your pupils (see Table 1).

Purpose of this task. The purpose of these web-based materials is to present the inquiry cycle of general five inquiry phases to scientists and to provide scientists with descriptions and examples of the skills and practices involved in these phases. This way the web-based materials can support a shared and general language on what it means *in general* to do inquiry. The second purpose is to provide scientists with lively images of what it means to do scientific inquiry in a classroom.

Methodology. Two sources were used for these web-based materials: (1) the review of Pedaste et al. (2015) explaining the five general phases of inquiry, and (2) Ark of Inquiry deliverables 1.1: Description of inquiry approach that fosters societal responsibility, and 1.2: Instruments for evaluating inquiry experiences, skills and societal responsibility. The latter explains the evaluation system used in the Ark of Inquiry that assesses pupils' progress and levels of inquiry.

Description of the web-based materials developed. The web-based materials are organised according to the five phases of inquiry. Each phase is described along the skills that are part of it. After a short description of the phase and skills involved, a worked-out example illustrates the phase and skills in the classroom practice. These web-based materials are concluded with a table in which the five phases, skills and short examples are summarised (see Table 1) (see Appendix 8.14).

4.4 Web-based materials for parents

Introduction. One of the big challenges for the future of youth over Europe is to prepare them for Responsible Research and Innovation, i.e. to be ready for active participation in society, to be ready to develop technical solutions and to bring them in a position to find scientific answers to upcoming problems.

These are ambitious aims, given the limited amount of time that children spend attending science lessons in school, whereas the majority of their time is spent at home, together with their parents (Zimmerman, Perin & Bell, 2010). Based on this ascertainment, the Ark of Inquiry project aims to give parents an authentic participatory role in their children's inquiry activities. Of course, parents are not expected to become teachers or substitute teachers, but they are expected to become learning companions for their children. Hence, the Ark of Inquiry project will enable parents to stimulate their children and support them on the inquiry learning pathway.

Purpose of this task. The main purpose of this task is to convince parents of possibilities for supporting their children in learning natural science. It is an "open call" for inquiry learning in science for an audience who is normally not in contact with research in science education. Therefore, the web-based materials aim to provide parents with information: firstly, about the importance of scientific literacy, then to illustrate how the findings of academic research can be transferred into practical advices, and finally examples are given to illustrate the possibilities parents have in their everyday life to discover scientific issues together with their children.

Methodology. After a short general introduction to the theoretical framework and the aims of the Ark of Inquiry project, the expected role of parents is defined, describing how parents could support their children at home using a three-step strategy: posing questions, searching for evidence, and finding relevant equipment for experimentation. Reducing the complex sequences of inquiry learning processes is a common way of transferring results into practical application (e.g., Tiemann & Bley, 2011).

Description of the web-based materials developed. The materials that have been developed for supporting children's inquiry learning at home are structured around the key steps of this science learning approach. The presentation of the materials begins with an overview of the aims of the Ark of Inquiry project, followed by a representative example of an inquiry activity to illustrate how inquiry looks like, and finally practical suggestions on how to help children at home are provided (see Appendix 8.15 through Appendix 8.18).

5. How are the web-based materials informed by and connected with the work undertaken within the context of the rest of the Work Packages of the project?

In developing the web-based materials for each stakeholder, a serious attempt was made to ensure that the content of the materials would be relevant to and consistent with the content/rationale of the rest of the work packages and the deliverables developed within the context of the work packages so far. To verify coherence among the project's deliverables and the present one, we used

- the *Description of inquiry approach that fosters societal responsibility* (D1.1) for the development of the web-based materials that relate to the definitions of inquiry and RRI and the phases of inquiry that learners go through during their engagement in inquiry activities (see web-based materials for teachers, scientists, and parents),
- the *Criteria for selection of inquiry activities including societal and gender dimensions* (D2.1) and the *Pedagogical inquiry scenarios for re-use of inquiry activities* (D2.2) for the development of the web-based materials that pertain to how an inquiry-based curriculum looks like (see web-based materials for teachers) and description of inquiry through an example of an inquiry activity (see web-based materials for parents),
- the *Specification of support systems in Ark of Inquiry* (D1.4) for the development of the web-based materials that relate to the several types of support and means to provide constructive feedback to pupils in the Ark of Inquiry activities (see web-based materials for teachers) and the support that parents can use with their children at home (see web-based materials for parents),
- the *Instruments for evaluating inquiry experiences, skills and societal responsibility* (D 1.2) for the development of the web-based materials that concern how/when/why to prompt teachers to reflect on their evolved understanding of inquiry and inquiry approach (instruction) and a showcase of instruments to capture teachers' initial, evolving and final understanding of various underpinnings that relate to inquiry and teaching science as inquiry (see web-based materials for teacher educators/researchers).

6. Conclusions

In this deliverable, a presentation of the theoretical background, the methodology followed, and the actual web-based materials that were developed as means to support and guide the productive engagement of four key stakeholders (teachers, teacher educators/researchers, scientists, and parents) in the Ark of Inquiry project has been provided. We anticipate that the web-based materials will contribute to the creation of a mechanism that can ensure the sustainability of the Ark of Inquiry both during and after the project. These materials are expected to be used as a point of reference for all stakeholders in the following ways. First, teachers can use them for gaining insight into or refresh their understanding of the important aspects of inquiry learning and teaching, both during the face-to-face training sessions and their teaching practices that will follow their training. Second, teacher educators can integrate the web-based materials in the design and implementation of professional development courses for teachers. Third, scientists can use the web-based materials to expand their understanding of how their everyday inquiry activities can be transferred for learning purposes during designing and implementing instructional settings. Finally, given that parents will not receive any formal training on aspects related to inquiry learning, the web-based materials, written in a language that is easy to comprehend, are expected to serve as supportive materials in helping parents monitor and scaffold their children's inquiry activities at home.

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8. Appendices

Appendix 8.1 Web-based materials for Teachers

Right below we provide the content of the web-based materials for Teachers as they appear on the Ark of Inquiry website [see www.arkofinquiry.eu/teachers].

Dear teacher,

In the context of Ark of Inquiry project, you are considered as one of the fundamental stakeholders who will play a key role in facilitating pupils' engagement in inquiry activities. To enhance your role and contribution towards this direction, we developed several web-based materials that will help you familiarize yourself with:

- the definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry,
- the phases of inquiry that learners go through during their engagement in inquiry activities,
- how an inquiry-based curriculum looks like,
- skills and practices involved during inquiry learning,
- several types of support and means to provide constructive feedback to pupils in the Ark of Inquiry activities.

Appendix 8.2 Web-based materials for Teachers: Definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry

What is Responsible Research and Innovation (RRI)?

Responsible Research and Innovation (RRI) has been defined as an inclusive approach that allows several societal actors (e.g., researchers, citizens, policy makers, business, third sector organisations etc.) to interact during engaging with research and innovation process with the express purpose to align both the process and its outcomes with the values, needs and expectations of European society (Science with and for Society, 2014). More specifically, citizens in democratic societies are expected to engage in decisions regarding new technologies when cultural, environmental, social, economic or ethical values are at stake. Preparing citizens to engage constructively in discussions about whether a new technology is beneficial or harmful to society requires providing them with a basic understanding of how to evaluate scientific research and innovation. Thoughtful and informed thinking comes from making judgments about the credibility of different types of evidence. Citizens need to be skilled in asking critical questions, evaluating qualitative and quantitative data, and discussing RRI issues with a variety of societal actors. Discussing science policy issues with a variety of stakeholders ensures that citizens are exposed to information from different perspectives. Likewise, interacting with a diversity of stakeholders increases the likelihood that persons in positions of authority feel a sense of responsibility to carefully consider socio-scientific issues. A greater involvement of informed citizens in the research and innovation process fosters inclusive and sustainable outcomes that ensure public trust in the scientific and technological enterprise. Although RRI is related to and relevant for all scientific domains, it has been argued that especially in the STEM domains in which emerging technologies encounter ethical questions and choices, RRI awareness is important (e.g. Sutcliffe, 2011).

The Ark of Inquiry project aims to foster RRI by teaching pupils core inquiry skills needed to evaluate the credibility and consequences of scientific research and by offering opportunities for pupils to engage with different societal actors involved in the research and innovation process. It is important that pupils experience inquiry activities outside of the formal educational setting and become aware of the broader community of people involved in research and innovation. Pupils who have an early opportunity to interact with a broad audience of stakeholders will be better prepared later as citizens to debate and think about scientific issues with an open and critical mind considering what have been mentioned as typical RRI aspects such as the global and sustainable impact of research findings and innovations in which positive and negative consequences are balanced, societal relevance, and the importance of participatory design and co-creation with end users (Sutcliffe, 2011). Communicating and sharing ideas develops awareness and understanding among all participants. Preparing future citizens for their role as active and informed participants in RRI therefore requires emphasising the importance of communication and dialogue. In the Ark of Inquiry project this aspect is highlighted by including inquiry activities where pupils must interact with a range of stakeholders such as science centre staff, university researchers, teacher education pupils, and citizens/end users. For instance, pupils can be asked to write about inquiry activities and outcomes as journalists of science, hence seeking debate with others about research findings.

What is Inquiry?

Inquiry “as a term” is defined in many resources using different viewpoints. The meaning of inquiry refers mainly to “asking questions”. However, the inquiry is not a simple word to explain using just “asking question”. Inquiry can be defined as an RRI process that aims to obtain scientific knowledge, resolving doubt, or solving a problem. It is actually an approach to the chosen themes and topics in which the posing of real socio-scientific questions is positively encouraged, whenever they occur and by whomever they are asked (Wells, 2001). More specifically, inquiry is an approach to learning that involves a process of exploring the natural or material world, which in turn leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding. Inquiry, in the context of science education, should mirror as closely as possible the enterprise of doing real science (National Science Foundation, 2000).

Appendix 8.3 Web-based materials for Teachers: Phases of inquiry that learners go through during their engagement in inquiry activities

The Ark of Inquiry project is a European Union funded project that seeks to build a scientifically literate and responsible society through Inquiry-Based Science Education (IBSE). The project, that lasts four years, aims at sharing engaging inquiry activities across Europe and providing pupils with meaningful feedback to improve their inquiry proficiency.

Further to the definitions about inquiry and inquiry learning that the Ark of Inquiry website entails, we elaborate here on each inquiry phase by describing the processes that take place during each phase of inquiry and illustrate how they are interconnected and relate to each other. These phases are described in five distinct dimensions: Orientation, Conceptualisation, Investigation, Conclusion, Discussion and seven sub-phases: Questioning, Hypothesis Generation, Exploration, Experimentation, Data Interpretation, Reflection, and Communication.

The following Figure illustrates the relations and connections among the different inquiry phases (Figure 1).

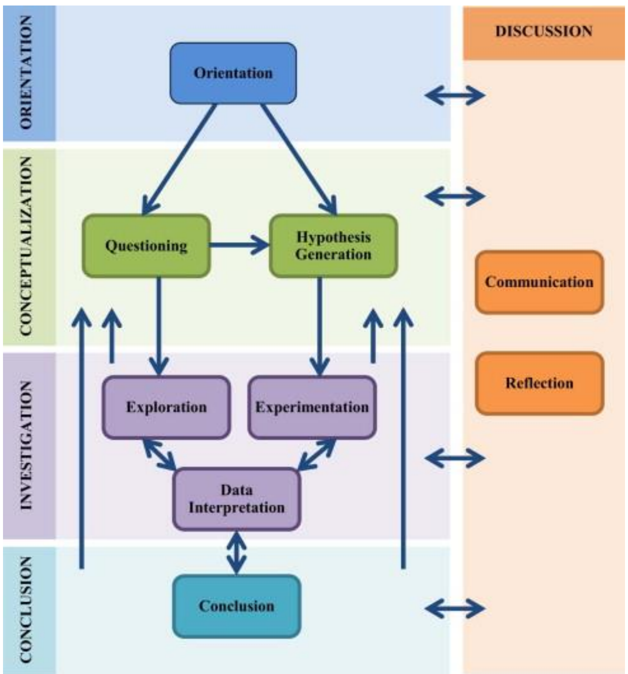


Figure 1. Inquiry learning framework [from Pedaste et al. (2015)].

Each phase of the inquiry learning framework is described below.

Orientation phase: Inquiry begins with this phase. The main aim of this phase is to stimulate curiosity about a topic and provide pupils opportunities to define a problem statement. As a teacher, your main aim is to find issues and topics which are relevant to your pupils.

Conceptualisation phase: This is the phase during which research questions and/or hypotheses are stated. As a teacher, you need to encourage your pupils to define research questions or hypotheses. This phase includes two sub-phases: Questioning or Hypothesis Generation sub-phase. The difference relates to the familiarity of pupils with the theory that underlies the topic under study. If pupils have little to no background, then they should start with the Questioning sub-phase (which subsequently guides them to the Investigation phase via the Exploration and Data Interpretation sub-phases). After acquiring experience with the topic the pupils can return and select the Hypothesis Generation sub-phase. Alternatively, pupils who are familiar with a topic could move from the Questioning to Hypothesis Generation sub-phase, if they had already collected enough background information to formulate a specific hypothesis. In any case, Hypothesis Generation is an important phase because it leads to the Experimentation sub-phase.

Investigation phase: Investigation phase is based mostly on hands on activities. It is a process of gathering empirical evidence to answer the research question or hypotheses. For example, the pupils work in groups in science laboratory to find evidence for the problem statement defined at conceptualisation phase. Investigation phase includes three sub-phases, which are exploration, experimentation and data interpretation.

Conclusion phase: In this phase, research findings from investigation phase are reported and justified by the results of the investigation. As a teacher, your role is to encourage your pupils to communicate with their peers to present their findings and results of their investigation.

Discussion phase: This phase of inquiry is directly connected to all the other phases. It consists of communicating partial or completed outcomes, as well as reflective processes to regulate the learning process. Discussion phase includes two sub-phases: communication and reflection. The communication sub-phase generates support for scientific research or study, or to inform decision-making, including political and ethical thinking. The reflection sub-phase aims to meaningfully raise pupils' skills in developing creative, scientific problem-solving and socio-scientific decision-making abilities.

Appendix 8.4 Web-based materials for Teachers: How does an inquiry-based curriculum look like?

A description of a curriculum that was designed by the University of Cyprus group, which pertains to the topic of "boiling and peeling eggs", is presented. The curriculum materials are grounded on the inquiry learning framework suggested by Pedaste et al. (2015). Learners engage in multiple inquiry-cycles through the curriculum. They discuss the progress of their work with the course instructors during "check-out points" placed in specific points in the curriculum. During these checkout points, the instructors aim to engage learners in semi-socratic dialogues, instead of merely answering questions or providing the correct answers to the activities of the curriculum. We extensively describe below what learners (working in groups of 4) do in each phase of the inquiry cycle in order to highlight how the Pedaste et al. (2015) inquiry learning framework can be used to inform the design of an inquiry-based curriculum.

''Boiling and peeling eggs''

Orientation phase: The learners are provided with a scenario that relates to a chef's daily task about boiling and peeling eggs for the customers of his restaurant. Because of the difficulties he encounters during performing this task (e.g., quite often the eggs are not hard boiled enough and thus they are neither easily peeled nor are uniformly peeled), learners are prompted to find solutions to the chef's problem by answering the following driving question: "How one can make perfect hard boiled eggs that are easy to peel?" They define the problem that merits solution, identify the variables that might affect the boiling and peeling of eggs, perform some reading and study from internet resources to get familiar with the context of the problem, and collect information about the processes that take place during the boiling of eggs (e.g., protein denaturation).

Conceptualisation phase: This phase begins by asking learners to formulate investigative questions. First, they are prompted to fill in the blanks in given investigative questions that the independent and depended variables are omitted. An example would be "Does the……… affect the …….? After learners have correctly completed the blanks with the variables that they need to test later, they are asked to identify themselves the syntax of an investigative question. At this point they are informed that any investigative question follows the same format and it always entails two variables (the one that will be varied (independent variable) and the one that will be measured (dependent variable) during the experiment) that are connected through the verb "affect". Then, they formulate new investigative questions themselves, without providing their syntax. In this way, the scaffolding of formulating an investigative question is fainting out.

Next, the learners are supported in developing hypotheses that derive from their investigative questions. In doing so, they are prompted to provide a possible explanation of the relationship for the two variables that each of the previously investigative questions entail. Right after, they receive through the curriculum epistemic-oriented scaffolds on a definition of a hypothesis (e.g., «a hypothesis is a plausible explanation for an observed phenomenon that can predict what will happen in a given situation»), and also, on the syntax that can be used for formulating their hypothesis (e.g., "If Variable A *increases/decreases*, then Variable B will *increase/decrease/remain constant*" or "The *more/less* the variable A is, *the more/less* the variable B will be''). In order to apply what they have learned about hypothesis generation, the learners are encouraged to formulate hypotheses based on the identified variables that might affect the boiling and peeling of eggs.

As a follow-up activity, learners are provided with 9 statements (3 hypotheses, 3 predictions, and 3 guesses in the context of boiling and peeling eggs), and they are asked to discuss with their peers and identify those that entail an explanation of how and why a phenomenon functions (i.e., hypotheses), those that point to the outcome of an experiment (i.e. predictions) and those that are mere guesses.

Investigation phase: This phase was developed according to three inquiry levels: Level A (basic inquiry), Level B (advanced inquiry) and Level C (expert inquiry). In every level, pupils design and perform a controlled experiment to answer their question and test their hypothesis.

Level A

In the first experiment, the investigative question "Does the egg's age affect the boiling and peeling of eggs?'' is given in order all groups of pupils to conduct the same experiment. Initially, learners are prompted to suggest a controlled experiment for answering the given investigative question without receiving any scaffolds on how to perform this task or feedback on their experimental design proposal, since the purpose of this activity is to enable the elucidation of learners' prior conceptions and level of skill acquisition about the design of controlled experiments. Next, the learners are engaged in a structured activity sequence through which they are scaffolded in identifying the variable that needs to be varied in their experiment (i.e., the age of the eggs), the variables that need to be kept constant, and the variable that has to be measured (i.e., the boiling and peeling of eggs). For each of the identified variables, the learners are prompted to specify how this would be treated for the purposes of their experimental design. For instance, for the peeling variable, the learners are expected to describe a procedure through which the peeling percentagee can be measured. As soon as each group of pupils finalises their experimental design and receives feedback from the instructors, they make a prediction (e.g., what is the anticipated outcome of the experiment) and a hypothesis (e.g., provide an explanation to justify their prediction) based on the investigate question, and then they proceed in performing their experiment. In doing so, they are expected to choose two eggs of different age (e.g., a 3 day egg and a 15 day egg), keep all other variables constant for both eggs (e.g., eggs' mass and volume, both eggs should originate from the same hen, the volume of the water that each egg would boil in should be the same, etc), and after boiling and peeling both eggs, they should record data about the peeling percentage of each egg. At this stage, the learners plot their data using the most appropriate means for their representation (e.g., a line graph, a bar chart, etc) and they are prompted to interpret their data in relation to their investigative question, and verify whether their predictions and hypotheses are confirmed or rejected.

Before proceeding to the Conclusion phase, the learners are engaged in two activities that serve as extensions to the development of their experimental design skill. The first activity pertains to a given experimental design in the context of ''peeling and boiling eggs'' that does not meet the requirements of a control experiment (e.g., there are more than one variables that are altered during the experiment), and learners are asked to comment on whether the given experimental design refers to a controlled experiment and suggest improvements in order to correct its flaws. The same activity is repeated with a new experimental design in a new context and learners again are asked to identify the experimental flaws and suggest improvements.

The second extension activity concerns learners' initial experimental design that was suggested in the beginning of the Investigation phase. In order to help learners evaluate the development of their understanding about the design of valid experiments, they are asked revisit their initial experimental design in order to assess whether their experimental design was valid or not. In the case they find that their experiment was not valid, they are prompted to suggest improvements. As a follow up activity, they are asked to define the steps they should be followed in designing and conducting valid experiments.

To help peer interaction and communication in order to check whether each group of learners reached at the same interpretations based on the data collected, they are asked (as a group) to upload their collected data in a google form that is open for public view. This will enable learners to compare their data with the data derived from their peers' experimental designs and use them for secondary analysis and new interpretations.

Levels B and C

The structure of activity sequence described for Level A is repeated for Level B (advanced inquiry) and Level C (expert inquiry) during which learners choose new investigative questions and subsequently design and conduct new experiments. The difference between each level lies on the type of supports and scaffolds that learners receive throughout the curriculum. Specifically, during Level B learners are asked to formulate the investigative question they are about to test themselves, and then they are provided with a table on which they have to define the variable that should be tested, the variables that should be kept constant, and the variable that should be measured. For each of the variables they are asked to define and specify the ways they will manipulate them during performing their investigation. They are also asked to formulate a hypothesis and subsequently a prediction, based on their investigative question. For each of these tasks, the learners are provided with some hints that point to specific activities that were implemented at a prior stage at the curriculum during Level A in case they need help on how to perform a specific task or refresh what they have already learned during Level A. During working with Level C activities, learners are asked to formulate a new investigative question and they are let to decide what to do for answering it. They are provided with enough space to organise their work in a similar manner they were instructed to do during Level A and Level B activities.

Conclusion phase: Learners draw conclusions based on the data collected during the preceding phase. Specifically, they create a two-column table to distinguish the variables that were found to affect the boiling and peeling of eggs from those that do not affect. This table will be informed from conclusions that will be made during the subsequent inquiry cycles through which the learners will seek to respond to other investigative questions pertaining at new variables that might affect the boiling and peeling of eggs.

Discussion phase: Learners prepare a poster in order to communicate their findings with their peers. In doing this, they need to think of ways to illustrate how they worked as a group during each phase of the inquiry cycle and decide the data and the way these should be represented within their poster. Once they finished their poster, they are asked to organise a 5-minute presentation for their peers as a means to communicate the procedure they applied. Additionally, they are prompted to reflect on (i) the process of inquiry followed during working with the curriculum materials, (ii) the practical difficulties and problems they encountered with during each of the inquiry phases, and (ii) report on possible changes that would follow if they were about to further investigating the boiling and peeling of eggs.

Appendix 8.5 Web-based materials for Teachers: Skills and practices involved during inquiry learning

When using the Ark of Inquiry in teaching your pupils about inquiry it is necessary to know which skills and practices are involved so you can see, stimulate and evaluate those skills and practices during working with the Ark of Inquiry in your classroom. Although most people agree on inquiry being a cyclic process in which pupils go through different inquiry phases there still is a lot of variation between models of inquiry. Pedaste et al. (2015) tried to solve this problem by comparing and analysing 32 articles describing inquiry models. This resulted in the recognition of five general inquiry phases that are distinctive for all inquiry cycles. These five inquiry phases each involve different skills and practices for pupils to learn and do (see Table 1). In this document we shortly describe the five phases of inquiry, the skills involved in the five phases, and provide you with short examples of classroom practice.

In the inquiry cycle presented here *three perspectives on inquiry* have been included:

1. a cognitive perspective: the knowledge and skills involved in doing inquiry;
2. a metacognitive perspective: the scientific awareness (SA) of inquiry as a process;
3. a societal perspective: awareness of inquiry as a process involving relevance issues, consequences and ethics related to yourself, others and society as a whole (RRI: Responsible Research and Innovation).

The first three phases of doing inquiry focus on the development of cognitive skills, some phases include skills related to the development of scientific awareness (SA). The last phase of the inquiry cycle focuses on developing an attitude of societal responsibility (RRI).

Skills and practices for each inquiry phase

<u>Orientation</u>

- *explore topic*
- *state problem*
- *identify variables*

Inquiry starts with orientation, during which pupils get an idea about the topic which is introduced by the environment, given by the teachers or defined by the pupil. Pupils interest and curiosity for this topic is stimulated, they get more acquainted with the topic and the main variables are identified. The outcome of this phase is a problem statement which gives direction for the next phases (Pedaste et al., 2015). Skills that need to be developed or stimulated with your pupils are curiosity, ability to explore a topic, to state problems and to identify variables that matter in their investigation.

A representative example that illustrates how skills and practices can be attained during the Orientation phase is provided below.

The teacher opens the window and throws out a ball of paper. She waits for or asks the pupils to react (before she puts the paper in the wastebasket). By this introduction the teacher has started a discussion about environmental pollution, waste and preserving the earth. After the discussion she lets pupils search for information about the current situation regarding environmental pollution and what can be done to stop pollution. Pupils share their findings in a classroom mindmap. At the end of the lesson they present the mindmap and conclude that environmental pollution is a big problem and that every individuals (every pupil) behavior (independent variable) can contribute to preserving or polluting the earth/environment (dependent variable). The teacher asks her pupils "do we know what we can do to help preserve the earth?"

<u>Conceptualisation</u>

- *raise questions*
- *identify hypothesis*
- *research plan*

During conceptualisation, pupils should be provided with the opportunity to determine the key concept that will be studied during inquiry learning, driven by either questioning or hypotheses (Pedaste et al., 2015). A pupil with less experience with the topic will first formulate questions based on the problem statement before moving on to hypotheses. Both of these should be based on theoretical justification and contain independent and dependent variables. Pupils learn to raise research questions and identify testable hypotheses. They also learn and practice to make a plan for their investigation necessary for answering the research questions or test the hypotheses. The outcomes of conceptualisation are research questions and/or hypotheses to be investigated and a research plan to answer these questions/hypotheses.

A representative example that illustrates how skills and practices can be attained during the Conceptualisation phase is provided below.

The teacher asks pupils to think of aspects they can change in their behavior and which contributions these changes would have in lessening environmental pollution. Each pair of pupils thinks of one thing they would change in the next two weeks and predict what outcome this will have. Josh and Steven always come to school by car and want to ride their bike to school the next two weeks. They formulate the question: What is the difference in CO_2 discharge if we ride our bikes to school the next two weeks instead of driving by car? They also think that if they go to ride their bike to school every day, their classmates will follow their example which can lead to even *less CO_2 discharge. Therefor they also make the following prediction (Hypothesis). If we ride our bike to school every day for two weeks the CO_2 discharge will become even less than our own car rides would produce because our classmates will start following our example. Josh and Steven make a plan for investigation They will ride their bike to school for two weeks, calculate what CO_2 discharge they will not produce during this period of time by mixing information about the route to school and characteristics of their parents cars. They will ask their classmates after one week, and after two weeks if they have been using their bike more often to come to school instead coming by car, how much more and what is the reason for any change. For the classmates that have made a change because of them setting an example they will also make the same calculation as they made for themselves.*

Investigation

- *collect data*
- *analyse data*
- *formulate findings*
- *SA: monitor*

The investigation phase follows the conceptualisation phase and is the phase where curiosity is turned into action in order to respond to the stated research questions or hypotheses (Scanlon et al., 2011). The first step is to collect data to find answers to research questions and/or hypotheses. Pupils then move to data analysis by organising and interpreting their data. During the process of collecting and analysing it is important that pupils have the skills to systematically collect data, follow and monitor their research plan and make well-founded changes in this plan if necessary. Pupils learn to search for relevant information, systematically collect relevant data and organise their data in order to help them answer their research questions or test their hypothesis. During data analysis pupils learn to make meaning out of their collected and organised data and to compare and contrast their findings against each other, as well as against other findings. Gradually, they learn to synthesise findings and recognise patterns in their data that can be formulated into findings.

A representative example that illustrates how skills and practices can be attained during the Investigation phase is provided below.

Josh and Steven have collected data following their plan. To show their results they have made 'before and after' tables regarding their own CO_2 discharge and the CO_2 discharge of their fellow pupils who also rode their bike to school. The outcomes of the interviews were clustered and counted.They formulate as a finding that their own CO_2 discharge has lessened with 0,395 ton. Three of their classmates have also chosen to ride their bike so they can ride with them to school. (0,689 ton CO_2 less).

Conclusion

- *draw conclusions*
- *relate findings*
- *SA: evaluate*

In this phase the outcomes of the investigation phase are turned into main conclusions. By relating those findings to their reseach question(s) and/or hypotheses pupils learn to decide what these conclusions actually mean. During the conclusion phase, pupils learn the ability to infer the answers to their research questions or arguments for rejecting or supporting their hypothesis from their data (Pedaste et al, 2012). After reaching conclusions and answering the research question, the entire inquiry cycle is critically evaluated in order to determine the solidness of the research findings.

A representative example that illustrates how skills and practices can be attained during the Conclusion phase is provided below.

> *Josh and Steven were able to answer their question 0,395 ton + 0,689 ton = 1.084 ton less.discharge in two weeks. They found their hypothesis supported by their findings but also learned during their interviews that 12 more pupils started to ride their bike not because of their example but because of the schoolproject. These pupils were not part of their research but did surface in their investigation. Josh and Steven conclude that a school project might have a bigger impact then setting the example, they regret not involving this variable.*

Discussion

- *RRI: relevance*
- *RRI: consequences*
- *RRI: ethics*

On the one hand, the discussion phase can be seen as an ongoing process related to all other inquiry phases involving communication about and reflection and discussion on the process and outcomes of the inquiry process along the way (Pedaste et al., 2012). On the other hand, when the actual inquiry process is finished it is time to communicate to a wider audience on the relevance, consequences, and ethics of those findings. IN this last phase, therefore, special interest is paid to learning to reflect on, communicate and discuss their inquiry activities and findings to peers, teachers, and society. For the purpose of communication, pupils learn to share research findings by being able to articulate the own understandings of the research answers or hypotheses. They also learn to listen to others sharing their findings or commenting on yours. To communicate well, pupils must be able to reflect on (specific parts of) the inquiry process, and point out the relevance, consequences and ethical issues related to it. They need to be able to receive and provide feedback, and by doing so become part of a community of inquirers that encompasses ongoing discussion fed by scientific research.

A representative example that illustrates how RRI components can be attained during the Discussion phase is provided below.

> *Josh and Steven present their findings to their classmates and listen to the presentations of their peers. They receive and give feedback on research processes and outcomes. They answer questions and give arguments for their choices. Together with their peers they formulate the relevance and consequences of their joined findings. What can be learned about human behavior and environmental pollution based on all research projects? After this they talk about what more they can do to communicate about their findings to others but decide that they first have to do more research within bigger groups to be sure that they can inform and advice others based on their findings.*

Table 1. Skills and Examples of the Phases of Inquiry Learning

Inquiry phase	**Skills**	**Examples**
Orientation	Explore topic	Find out what is the current situation on environmental pollution
	State a problem	We don't know what we can do to preserve the earth
	Identify variables	Human behavior (independent) & Environmental pollution (dependent)
Conceptualisation	Raise questions	What is the difference in CO2 discharge when we ride our bike to school?
	Identify hypothesis	The difference in CO2 discharge will be more than our own expected discharge because our classmates will follow our example
	SA: Research plan	We will calculate the difference in CO2 discharge
Investigation	Collect data	Interview fellow pupils and make calculations
	Analyse data	Table shows CO2 discharge before and after
	Formulate findings	1.084 ton less.CO2 discharge in two weeks
	SA: Monitor	Follow research plan and make well-grounded changes when needed
Conclusion	Draw conclusions	We were able to decrease the CO2 discharge by riding our bikes and our friends who followed our example
	Relate findings	If we want to decrease CO2 discharge a school project has more effect then setting the example
	SA: Evaluate	Next time it would be interesting to investigate the results of a school project about pollution on the CO2 discharge

Discussion	RRI: Relevance	Steven tells his classmates that they should organise a school campaign to persuade more pupils to ride their bike to school based on the outcomes of their research
	RRI: Consequences	Josh tells in his presentation that his research results are important because they show that everyone can make a difference in preserving the earth by making small changes in their habits
	RRI: Ethics	Josh says to Steven that they cannot oblige their fellow pupils to ride their bike based on this research alone

Each skill matching the phases of inquiry described in table 1 have different proficiency levels described from A-level (Novice) to C-level (Advanced) in the evaluation system of the Ark of Inquiry.

Appendix 8.6 Web-based materials for Teachers: Several types of support and means to provide constructive feedback to pupils in the Ark of Inquiry activities

It has been documented for years that learners can attain deeper understanding of science concepts and processes, if they are given opportunities to actively participate in inquiry-driven activities. At the same time, evidence from the literature indicates that because inquiry is a rather cognitive demanding activity that increases pupils' cognitive load, pupils will be needing substantial supports to "…become knowledgeable about content, skilled in using inquiry strategies, proficient at using technological tools, productive in collaborating with others, competent in exercising self-regulation, and motivated to sustain careful and thoughtful work over a period of time" (Krajcik, J., Blumenfeld, P., Marx, R., & Soloway,E., 2000, p. 1). The purpose of this report is to provide information about ways to aid pupils via several types of supports during their participation in inquiry-driven activities, and also, how teachers can provide constructive feedback on pupils' work in progress. The supports and the feedback mechanisms will be presented along the four phases of the inquiry learning cycle framework proposed by Pedaste et al. (2015).

<table>
<tr><th colspan="2">Inquiry Phase</th></tr>
<tr><td colspan="2">ORIENTATION
The process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement</td></tr>
<tr><th>Sub-phases</th><th>Type of support and provision of constructive feedback</th></tr>
<tr><td></td><td>Pique pupils' curiosity and generate their interest through inviting them to express themselves of what they know about the topic that has been presented.
Determine pupils' prior knowledge and understanding of the concepts or ideas that relate to the presented topic through asking/probing questions or inviting pupils to raise their own questions.
Ask pupils to form groups so that collaborative discourse can be enhanced. It is also a means through which pupils will build shared understandings of ideas and of the nature of the discipline with their peers.
Prompt pupils to create concept maps through which their understandings about the problem's variables and ideas can be elicited. Concept maps are also excellent means that facilitate pupils</td></tr>
</table>

<table>
<tr><td></td><td>tracking of concepts that are being explored during inquiry.

As their investigations progress, prompt pupils to revisit their initial concept maps to integrate new information with previous understandings. This is a fruitful way to make pupils aware of the development of their conceptual understanding.

• Provide adequate time for pupils to puzzle through the given problem.

• By the end of orientation phase, make sure that pupils can describe the problem that has been presented in their own words and prompt them to state the driving question that departs from the problem description. A driving question entails “a need to know” and guides pupils through inquiry to find solutions to a question. The rationale for engaging pupils in defining a driven question departs from the notion that such an activity enhances and maintains pupils’ interest, directs them toward their investigation goals, and addresses authentic concerns. The driving question will help pupils during the following phase (conceptualisation) in which research questions or hypotheses will be formulated.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Inquiry Phase</td></tr>
<tr><td colspan="2">CONCEPTUALISATION

The process of stating theory- based questions and/or hypotheses</td></tr>
<tr><td>Sub-phases</td><td>Type of support and provision of constructive feedback</td></tr>
<tr><td>Questioning

The process of generating research questions based on the stated problem</td><td>• Provide scaffolds to pupils to formulate their own research questions. Through these scaffolds make pupils aware of
    o why a research question is needed at this stage,
    o what is the syntax of a question that can be tested later,
    o how a research question/investigable question differs to common-use or open-ended questions
    o how an investigable question and a hypothesis relate and differ (for hypothesis see right below)

• Since pupils might not be familiar with the syntax of an investigable question, use the following heuristic: ask them to fill in the blanks in a given investigable question that the independent and depended variables are missing.

An example would be “Does the……… affect the …….?”

After pupils have completed correctly the blanks with the variables that they need to test later, it is important to inform them that any investigable question follows the same format and it always entails two variables (the one that will be varied and the one that will be measured during the experiment) that are connected through the verb “affects”.</td></tr>
</table>

	In a later stage, when pupils are going to test the effect of a new variable to the depended variable, it would be useful to ask them to formulate the investigable question themselves, without providing its syntax, and in case they fail to formulate it correctly, prompt them to visit to the previous investigable question, study its format and apply it to the new case. In this way, the scaffolding of formulating an investigable question should be fainting out, when pupils are comfortable in formulating the research questions on their own.
Hypothesis generation *The process of generating hypotheses regarding the stated problem*	Hypothesis generation can precede or follow the formulation of investigable questions. It is important at this stage to keep in mind that in science the term «hypothesis» is used differently than it is used in everyday language. In everyday language the term is used to denote an educated guess or an idea that we are quite uncertain about. On the contrary, in science «a hypothesis is much more informed than any guess and is usually based on prior experience, scientific background knowledge, preliminary observations, and logic» (Understanding Science, 2014). Additionally, a hypothesis is «a plausible explanation for an observed phenomenon that can predict what will happen in a given situation. A hypothesis is made based on existing theoretical understanding relevant to the situation and often also on a specific model for the system in question» (NRC, 2012, p. 67). That said, it is important to find ways to help pupils develop epistemic understanding of this concept, and also to be able to differentiate between hypotheses and predictions, since the two terms are quite often confused in textbooks and by teachers. Activities that might be used as supports for pupils in developing understanding of hypothesis as a concept and facilitate their competence in developing hypotheses within the context of the Ark of Inquiry context are as follows: • After pupils formulated investigable questions that would like at a later stage to test through designing specific investigations, ask pupils to write in the left column of a two column table their investigable questions and prompt pupils to write next to each investigable question an *explanation* of *how* they think the relationship of the two variables of each question is. Remind pupils that they should not focus on writing what the result of the planned experiment would be (this would be a prediction) or merely answering the investigable question by stating that Variable A affects/does not affect Variable B. For instance, if the investigable question is «Does the type of surface of a ramp affect the time of flight of a rolling down the ramp ball?», the pupils are expected to write something like «More rough surfaces will impede the ball from rolling on the ramp and thus the time of

	flight will be greater than in the case of ramps covered in smooth surfaces». • If the hypothesis formulation precedes the formulation of investigable questions, then follow the same format as the abovementioned activity, but in a reverse order. If pupils succeed in formulating hypotheses based on previous experience, scientific knowledge, and preliminary observations and their hypotheses relate to proposed explanations of how a phenomenon functions, then prompt them to write next to each hypothesis an investigable question through which their hypothesis could be confirmed or rejected. • If pupils fail to formulate hypotheses that are explanation oriented statements and their hypotheses are mere guesses or predictions, we can scaffold their understanding of the nature of hypothesis by providing three statements (a hypothesis, a prediction, and a guess) in the context they are experimenting with and ask them to discuss with their peers which of the three statements provides an explanation of how and why a phenomenon functions. This activity can be repeated several times with new statements until pupils appear to distinguish between statements that are explanations (and thus they are considered as hypotheses) and statements that relate to the outcome of an experiment (and thus they considered as predictions). The activity can be extended to new (or unfamiliar) contexts and pupils' success in differentiating between hypotheses and predictions will serve as an indicator of the development of their hypothesis formulation competence.
Inquiry Phase	
INVESTIGATION *The process of planning exploration or experimentation, collecting and analysing data based on the experimental design or exploration*	
Sub-phases	**Type of support and provision of constructive feedback**
Exploration *The process of systematic and planned data generation on the basis of a research question.*	Given that both Exploration and Experimentation sub-phases involve the design and implementation of an exploration or an experiment based on the investigable question and/or the previously formulated hypothesis, the suggested supports for both sub-phases are provided interchangeably. Quite often, pupils encounter difficulties during designing an experiment to test a hypothesis or answer an investigable question because they lack the control of variables skill. This skill pertains to a learner's competence in designing a valid experiment (or a fair test) within which only one variable is altered (that is the independent variable; the variable that its

Experimentation *The process of designing and conducting an experiment in order to test a hypothesis*	impact on the depended variable is tested) and all other variables that might influence the effect of the independent variable on the depended variable are controlled (or kept constant). Because pupils' experimental designs might pertain to uncontrolled experiments (e.g., more than one variables are altered or not all other variables are kept constant), pupils will need substantial support at this stage. • A heuristic that will help pupils in designing a controlled experiment is as follows: ask pupils to break down their investigable question into two parts; the part before the verb «affect» should entail the variable that needs to be altered in their experiment (the independent variable) and the part that follows the verb «affect» should contain the variable that has to be measured (the depended variable). Based on this breakdown, prompt pupils to choose which of the two variables is going to be altered and which is going to be measured in their experiment. After pupils' success in identifying both variables and how they should be treated within their experiment, prompt pupils to think of and discuss with their peers how the rest of the variables that might affect the experiment should be treated in their experimental design. Provide specific examples of variables and ask pupils to state whether each of these should be altered or kept constant during their experimentation. Through this approach the pupils should understand that in order to design a valid experiment, only one variable should be altered and all the other variables should be kept constant. • Before proceeding in executing their experiment, provide pupils with an experimental design that does not meet the requirements of a control experiment (e.g., tell pupils that this is an experiment designed by a group of pupils at your age) and ask pupils to comment on whether the given experimental design refers to a controlled experiment. If pupils have already developed the control of variables skill through the previous activity, then they should be able to identify the flaws of the given experimental design and suggest improvements in order to reach at a controlled experiment. This activity can be repeated with several experimental designs in other domains to the one that the pupils are working with, if we aim at examining the development and transfer of the control of variables skill in new domains. • Another domain that pupils encounter difficulties during the exploration and experimentation phases and need support concerns the planning and execution of their experiment. This difficulty relates to the absence of the skill of planning from their skills' repertoire. «Planning is a complex skill requiring experience and ability to think through to the possible outcomes of actions» (Harlen, 2012, p.15).

	It is suggested that young pupils can be introduced to planning by posing questions to them during the planning and execution phases like “tell me what you are going to do in this experiment” or «how are you going to change the variable A in your experiment, how are you going to measure variable B in your experiment», etc. Also, Harlen (2012) suggests that if the investigation is observational rather than experimental, it is important to prompt pupils to decide with their peers what would be important to observe during the execution of their experiment, how they will observe, and how they will collect their data. This is an important step in their planning, since pupils quite often fail to choose of a functional way to measure the effect of the variable they are testing on the dependent variable. For instance, in the context of kinematics, and specifically while investigating the factors that affect the time of flight of spheres that are rolling down a ramp, the pupils quite often suggest that a timer would be the best tool to measure the time of flight. However, given the relatively small size of the ramp, the pupils will not be able to reach at valid measurements. Hence, it is important to help them think of alternative ways that the time of flight can be achieved; for instance, we can prompt them to use their senses (both vision and hearing) in order to decide if two rolling down the ramp spheres reach the end of the ramp at the same or different time. This can be obtained easily by focusing on the nature of sound that emerges (e.g., a single sound indicates that both spheres reach the end of the ramp at the same time or two distinct sounds indicate a difference in the time of flight) and on the visual outcome of the spheres at the event of reaching the end of the ramp. • Another instructional technique that will support pupils’ engagement with the inquiry activity during the investigation phase is the predict-observe-explain cycle (POE) (White & Gunstone, 1992). Both predict and observe stages of the POE cycle concern the exploration and experimentation sub-phases of the investigation phase, whereas the explain stage applies to the data interpretation phase (see data interpretation sub-phase below). Prediction is an important aspect during pupils’ engagement with the investigation phase, because it increases their curiosity, motivation and anticipation of the outcomes of their designed experiment. To facilitate pupils’ formulation of predictions, we can ask them to draw on prior knowledge and state what will occur during their experiment, or what they might come up with at the end of their experiment. Pupils can be encouraged to make individual predictions, then share them with their peers, make arguments for their predictions and come to consensus of what is more feasible to happen when executing their experiment. It is important to let them know that in case strong arguments occur for two competitive predictions, then both predictions can be maintained and use the experimental outcome as a means for testing these predictions. This is an essential step in formulating their

	predictions, since pupils, especially the young ones, might feel uncomfortable in formulating a prediction that will be rejected at the end. Teachers' impact at this point is fundamental, since they can let pupils aware that they can pose a prediction in an attempt to model how they draw on their prior knowledge and experience to determine what might happen. This can be achieved by adopting the «thinking aloud» technique through which they can coach pupils in monitoring explicitly the process of formulating a prediction. • In general, during exploration and experimentation phases we need to help pupils remain on track with their investigable question or hypothesis and scaffold their efforts in designing and applying their experiments both conceptually and procedurally. Pupils should be reminded at certain points during their investigations to revisit their hypothesis or question and verify whether the data or evidence they are collecting is adequate or relevant to their initial plans and decide of when they collected enough evidence/data for answering their questions or verify/reject their hypothesis. • Additionally, because pupils are not familiar with the materials and infrastructure that are available in the science class, it is important, as teachers to anticipate what equipment and materials pupils might need while designing their investigations, show them what is available and tell them to make their selection from these equipment and materials when they have decided what to do. • Finally, given that the sub-phase that follows relates to data interpretation, it is advised to prompt pupils organise/represent the data collected in tables, graphs, etc in a such a way that the meaning making out of the collected data is facilitated through the medium selected for their representation. Hence, we can prompt pupils to select the best representational medium that fits with their data through providing examples of how the set of data can be organised. Of course, this presupposes that the pupils have an understanding of all these means of data organisation and representation. If not, this is another issue that the teachers need to address by introducing all these means to their pupils.
Data interpretation *The process of making meaning out of collected data and synthesising new knowledge*	Pupils will enter the data interpretation phase right after they performed their experiment through which they aimed to answer an investigable question or prove a hypothesis. In entering this phase they need to make sure that the data collected is correct (in the sense that the data concern the variables under study) and adequate for making meaning and synthesising new knowledge. Consequently, two critical questions that serve as a support at this stage could be as follows: «Did you collect the correct data that will help you in answering your investigable question or confirm/reject your initial hypothesis?», «Did you collect enough data that will help in answering your investigable question or confirm/reject your initial hypothesis?» If either or both questions are negative, then pupils should be encouraged to repeat their experiment until they are

satisfied with the set of the collected data. If pupils are ready to proceed in interpreting their data, then the following prompts can act as supports for their interpretations:

- *«What claims or propositions can you make that are supported by the evidence gathered?*
- *What tentative explanations might they come to?*
- *How do these compare with their starting assumptions and predictions?»* (Harlen, 2012, p.15)

In addition, during data interpretation pupils should be prompted to compare their predictions to the data collected and develop explanations about inconsistencies. This step will help pupils to better monitor the development of their understanding of the phenomenon under study, since through revisiting their predictions they are given an opportunity to access their original ideas and check whether these have been confirmed or not during their experimentation. Here again teachers can model how the generation of explanations is processed and consider whether the explanation is adequate, coach pupils as they develop explanations, and underline the necessity of taking into consideration various key features that derive from their data.

Another anticipated outcome of the data interpretation phase concerns pupils' ability to define the type of relation between the tested variables. In order to achieve this learning goal pupils should be able to draw inferences from the collected data about how the independent variable affects the depended variable. The nature of relation between the two variables is constrained by the type of variables that have been tested. The most common types of variables that pupils will encounter during their investigations are the *categorical* (sometimes called nominal), the *ordinal*, and the *interval*. A *categorical* variable is one that has two or more distinct categories, but there is no intrinsic ordering in the categories. For instance, color, gender, type of plants, etc are categorical variables, because each of them has a certain number of categories that cannot be ordered. An *ordinal* variable is similar to the categorical variable, but its categories can be clearly ordered. For instance, the ranking of objects according to their volume (e.g., small, medium, big) or the ranking of surfaces according to their transparency (e.g., transparent, semi-transparent, non-transparent) are ordinal variables, because their values can be ordered according to a specific criterion. Lastly, an *interval* variable is similar to the ordinal variable, but the intervals between the values of the interval variable are equally spaced (e.g., time, temperature, mass are examples of interval variables). Consequently, it is important to make sure that pupils can distinguish between the tree

	types of variables and also, to define the type of relation that appears to exist based on the evidence collected from their experiments. For instance, if both variables are ordinal or interval, the pupils should be scaffolded to define the relation as follows: “the more the variable A increases or decreases, the more the variable B is increases/or decreases”. If both variables are categorical (sometimes called nominal), then the type of relationship that is expected to be extracted should be a description of how specific values of variable A appeared to affect the values of variable B. To help pupils formulate a comprehensive relation between the variables, prompt them to describe first the data collected for both variables that have been tested, and then pose questions like «what happened to the value of variable B, when variable A was increasing or increasing», «how can we make a statement that will indicate the direction of the relationship between variable A and variable B»

Inquiry Phase	
CONCLUSION *The process of drawing conclusions from the data. Comparing inferences made based on data with hypotheses or research questions*	
Sub-phases	**Type of support and provision of constructive feedback**
	Pupils should proceed in the conclusion phase, after significant time was invested in the preceding phase during which pupils have made interpretations on the basis of the data collected during their experiments. Both the data interpretation and the conclusion phases are closely aligned, because the pupils are expected to draw conclusions based on their interpretations. The conclusion phase is also linked to the conceptualisation phase, because pupils should be able to compare inferences that departed from their data with their initial hypotheses or research questions. In doing this, pupils will need support and feedback on the conclusions they will be formulating, because this is not a straightforward procedure that they can follow on their own. To facilitate their work, we can ask them to revisit their investigable question and/or hypothesis and decide if their interpretations are aligned with their original questions or hypotheses. In case their original hypotheses is not supported, then they should be prompted to develop new hypotheses that would be consistent with the interpretation of the data that was undertaken during the previous phase. Again, questions like «What claims or propositions can you make that are supported by the evidence gathered?» or

	«What tentative explanations might they come to?» will help pupils formulate new hypotheses through which the relation between the tested variables can be explained. In case the data do not designate a relationship between the tested variables, then the pupils should be prompted to identify new variables whose effect would be tested and thus a new round of investigation can be initiated. If pupils encounter difficulties in identifying new variables, a heuristic that can be used to facilitate their work is to ask them revisit the conceptualisation phase and check if during that stage they have identified more than one variables that they would like to test their effect on the dependent variable. In the formulating their conclusions it may be useful to help pupils distinguish between claims supported by the evidence they collected (e.g. "the time of flight of a ball rolling down a ramp with a rough surface is greater compared to the time of flight of the same ball rolling down an identical ramp with a smooth surface") and explanations which are attempts to explain why or generalise from the specific claims (e.g. "I think this is because the friction force that is exerted on the ball at the rough surface is greater than the friction force exerted on the ball at the smooth surface").
Inquiry Phase	
DISCUSSION	
Sub-phases	**Type of support and provision of constructive feedback**
	Discussion transcends all the previous inquiry phases and sub-phases. It is an essential ingredient for promoting collaboration through the exchange of ideas at any point of the inquiry process. If needed, teachers should constantly remind to their pupils the value of mutually exchanging ideas and critiquing each other's work. Peer feedback has shown to be a valuable learning asset both for peer assessors and peer assesses (Hovardas et al., 2014).

Appendix 8.7 Web-based materials for Teacher Educators/Researchers

Right below we provide the content of the web-based materials for Teacher Educators/Researchers as they appear on the Ark of Inquiry website [see www.arkofinquiry.eu/teacher-educators].

Dear teacher educator, Dear researcher

In the context of Ark of Inquiry project, you are considered as one of the fundamental stakeholders who will play a key role in facilitating teachers' professional development in the inquiry approach (learning and teaching). To enhance your role and contribution towards this direction, we developed several web-based materials that will help you familiarize yourself with:

- how to support teachers in understanding and using the Ark of Inquiry materials both during teacher training and implementation,
- how teacher preparation successful practices in inquiry learning reported in the literature can inform the design of teacher professional development courses in the context of the Ark of Inquiry project,
- how/when/why to prompt teachers to reflect on their evolved understandings of inquiry and inquiry approach,
- a variety of instruments to capture teachers' initial, evolving and final understandings of various underpinnings that relate to inquiry and teaching science as inquiry.

Appendix 8.8 Web-based materials for Teacher Educators/Researchers: How to support teachers in understanding and using the Ark of Inquiry materials both during teacher training and implementation?

Capps, Crawford and Constas (2012) state that one of the key features of effective professional development for inquiry based learning/teaching is to have extended support for teachers, this is supportive measures besides the actual moments of training. This extended support is important because it offers teachers the opportunity to interact with others, ask questions and receive feedback about inquiry based learning/teaching outside the training sessions during their own implementation processes.

In the Ark of Inquiry teacher educators and researchers can play important roles in providing extended support to teachers. There are various ways of giving extended support (see Table 1 on the following page).

In addition, this web-based material also provides teacher educators and researchers with some first ideas on which questions teachers might have during training and implementation. For this purpose, three tables are presented that show teachers' frequently asked questions together with first ideas on their answers and the extended measures that could be applied to provide teachers with the answers:

Table 2: How to use the Ark of Inquiry during my lessons?

Table 3: How can I contribute to the Ark of Inquiry?

Table 4: How does the award system of the Ark of Inquiry work?

Table 1. Ways of support for teachers during training and implementation

Support systems	Examples
Organise classroom visits	Teacher educator/researcher or colleagues visit (Ark of) inquiry based lessons.
Evaluate materials	Teacher educator/researcher or colleagues look at and comment on developed materials or data from (Ark of) inquiry based lessons.
Organise Reunions	Meetings where teachers and teacher educators/researchers meet to interact about (experiences with) Ark of Inquiry.
Create digital community	Create an online community for teachers and teacher educators/researchers to interact about (experiences with) Ark of Inquiry.
Create chat rooms/threaded discussions	Make an online forum for asking questions about Ark of Inquiry.

Table 2. How to use the Ark of Inquiry during my lessons?

Question	Information	Extended support
How to choose Ark of Inquiry activities?	You can choose activities based on 7 selection criteria: 1. Domain 2. Topic 3. Language 4. Inquiry proficiency level 5. Inquiry phases 6. Age range 7. Learning time Pupils choose their activities (self-regulated learning) based on their skill levels and interests and discuss their choices with their teachers.	Evaluate materials: Together with the teacher evaluate if pupils have chosen the right activities based on the selection criteria.

Question	Information	Extended support
How to work with Ark of Inquiry activities during my lessons?	Pupils work individually or in groups on inquiry activities. The teacher's role is to monitor the process of pupils by assuring regular moments of formative and summative assessment. The teacher should pay attention to the discussion phase and facilitate presentations, discussions and support creativity and innovation.	Classroom visit: Plan a classroom visit to see how the teacher works with and experiences the Ark of Inquiry in his/her classroom
How to evaluate Ark of Inquiry activities?	Self-assessment, peer feedback and teacher assessment are collected in a pupil's portfolio. A portfolio contains: 1. Passport 2. Self reports 3. products 4. peer feedback 5. dialogue reports 6. summative assessment test In the portfolio pupils' progress along the framework of inquiry proficiency is measured. Inquiry proficiency is viewed to develop across three levels: novice, basic and advanced level of proficiency.	Evaluate materials: Together with the teacher go through some portfolios. Which general impressions, similarities and differences can be found?

Table 3. How can I contribute to the Ark of Inquiry?

Question	Information	Extended support
With which activities can I contribute to the Ark of Inquiry?	Inquiry based activities are suitable for the Ark of Inquiry when: 1. They promote inquiry learning in STEM domains 2. They are productive and engaging for pupils at various age and skill levels. 3. They are gender inclusive 4. They promote pupils' awareness of societal responsibility More specific, the activity: 1. already exists 2. is targeted between age levels 7 to 18 3. is in a STEM domain 4. supports inquiry learning 5. covers at least one inquiry phase 6. maps on a specific inquiry proficiency level 7. produces evidence on the success of the activity Recommended criteria are: 1. Supports responsibility and gender inclusion 2. Integrates learning content and inquiry skills	Evaluate mmaterials: Together with the teacher match different activities from the teacher to these criteria
How can I make my inquiry activities suitable for the Ark of Inquiry?	To make your activity suitable you first need to describe: - Language - Domain - Description of activity - Inquiry proficiency level - Covered inquiry phases - Inquiry phases deviating from proficiency level - Materials needed - Evidence produced - Copyright/other restrictions	Evaluate materials: Together with the teacher adapt an existing inquiry activity with the help of the scenarios, provide feedback.

	Additional recommended elements to describe are: - Title - Keywords - Topic - Typical age range - Typical learning time - Support for societal responsibility and gender inclusion - Targeted learning outcome If activities do not match all the requirements you can redesign the activity according to one or more scenarios: 1. Scenario 1: Mapping the activity to five phases inquiry model 2. Scenario 2: Changing the proficiency level 3. Scenario 3: Adding Inquiry phases 4. Scenario 4: Improving gender inclusion 5. Scenario 5: Overcoming language barriers	

Table 4. How does the award system of the Ark of Inquiry work?

Question	Information to answer these questions
Why is there an award system for the Ark of Inquiry?	The ark of Inquiry project wants to expand young people's awareness of responsible research and innovation. The award system is developed to challenge and stimulate pupils to become more responsible researchers and innovators. Especially the awareness of responsible research and innovation is awarded in this system
When do my pupils get an award for their work in the Ark of Inquiry?	The award system consists of five awards: at stage 1 an inquiry star and diploma celebrate the ability to individually reflect on the relevance, consequences and ethics of processes and outcomes of inquiry for oneself, others and society. At stage 2 bronze, silver and gold medals celebrate excellent communication and discussion about the relevance, consequences and ethics of inquiry processes and outcomes for oneself, others and society with an audience. Pupils can obtain up to all five awards during the time they participate in the Ark of Inquiry. IN total, 50% of all pupils is expected to obtain a star, 20% a diploma, 10% a bronze medal, 5% a silver medal, and 1% a gold medal. Together with their teachers pupils take active roles in getting nominated. Granting is organised by a national jury consisting of teachers, teacher educators and experts. The process of awarding is coordinated by a national administrator.

Appendix 8.9 Web-based materials for Teacher Educators/Researchers: How teacher preparation successful practices in inquiry learning reported in the literature can inform the design of teacher professional development courses in the context of the Ark of Inquiry project?

The purpose of these materials is to provide information to teacher educators and researchers about key features that were incorporated within the design and implementation of different professional development courses reported in the literature, in conjunction with teachers' learning outcomes that were revealed as a result to their participation to these courses. These, in turn, can be approached as examples of successful practices derived from the literature on teachers' professional development in inquiry learning. The presentation of these features begins with a summary of the characteristics of effective professional development programs in the field of general education (e.g., Darling-Hammond & McLaughlin, 1995; Loucks-Horsley et al., 1998) and in science and mathematics education (e.g., Garet et al., 2001; Penuel et al., 2007) prepared by Capps et al., 2012 (see Table 1). Next, we present examples of models or theoretical frameworks that were used for the design of professional development courses, along with their outlines, as well as how these courses affected teachers' change in conceptual understanding, beliefs, practices, etc (Table 3). Finally, in Table 3 we illustrate evidence to document how the critical features of effective inquiry suggested by Capps et al. (2012) were addressed in the design and implementation of a PD program for the purposes of the Ark of Inquiry project.

Table 1. Characteristics of effective professional development (adapted from Capps et al., 2012, pp. 296 - 297)

Darling-Hammond and McLaughlin (1995)	Loucks-Horsley et al. (1998)	Garet et al. (2001)	Penuel et al. (2007)
Engages teachers in concrete tasks of teaching, assessment, observation, and reflection	Emphasises inquiry learning, investigations, and problem solving	Focuses on content knowledge	Discusses alignment with local, state, and national standards
Engages participants in inquiry, reflection, and experimentation	Helps build pedagogical skills and content knowledge	Provides opportunities for active learning	Engages teachers in aligning activities with standards
Promotes a collaboration between participants and professional developers	Models the strategies teachers will use with their students	Connects to or is coherent with other activities	Emphasises content of particular curriculum during PD
Connects to or is coherent with classroom work	Builds learning communities where continued learning is valued	Engages teachers in reform-based PD	Provides ongoing, coherent PD
Sustains and continues support	Supports teachers in leadership roles	Promotes collective participation of teachers	Connects to reform-based practices
Connects to other aspects of school change	Links to the educational system (district initiatives, state curriculum, etc.)	Provides an adequate amount of time	
	Changes to insure positive impact		

Table 2. Examples from the literature about models or theoretical frameworks implemented in professional development courses, along with their outlines, as well as their impact on teachers

1. Inquiry-Based Demonstration Classroom (IBDC) in-service programme	
Model or Framework	Inquiry-Based Demonstration Classroom (IBDC) in-service programme: a model of professional development that aims to bring closer the ideal with the current in-service practices and to promote the practice of science as inquiry in the classroom.
Aims	To capture: a) changes in teachers' behaviors about inquiry instruction, b) changes in beliefs about inquiry instruction, c) beliefs about the inquiry-based in-service program, and d) differences between beginning and experienced science teachers in terms of their behaviors and beliefs about science instruction.
Outline of the professional development course (PDC)	The PDC entailed: a) a pre-program (one-day workshop that provided an orientation to inquiry-based science instruction), b) a program with several follow-up activities like visits to a classroom that followed an extended inquiry cycle in science or electronic discussions with the participants and the instructor/researcher, c) visits of teachers to one another and the demonstration teacher through which teachers were given opportunities to socially explore and reframe their beliefs and practices of extended inquiry instruction with their colleagues, d) the participants were exposed to a model of inquiry, implemented it in their classrooms, and made reflections of the enacted lessons.
Outcomes	a) changes in beliefs and behaviors of the experienced teachers, b) the participants made statistically significant changes in their extended inquiry practices, but no statistical significant changes in their beliefs about inquiry were revealed, c) participants made significant change in their assessment of inquiry instruction, and at the same time their students improved in communication and activity because of their engagement with extended inquiry cycles, d) developing researchable questions, designing and conducting investigations, and sharing the results of investigations were some of the skills that the students of the participating teachers appeared to have significantly mastered.

Reference	Luft, J. A. (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. International Journal of Science Education, 23(5), 517-534.
2. ENVISION professional development model	
Model or Framework	ENVISION professional development model: a) builds on active teacher involvement in inquiry and inquiry-based teaching, b) integrates learning environmental science content through inquiry with learning to teach science through inquiry, c) gives teachers an opportunity to adapt themselves with elements of classroom inquiry while learning environment related concepts.
Aims	To enhance teachers' understandings about inquiry-based study of local environmental problems, teaching science through inquiry, environmental science content knowledge, and inquiry skills and abilities.
Outline of the professional development course (PDC)	The participating teachers were engaged in three basic types of inquiry activities: field studies/environmental monitoring, investigative laboratories and models, and environmental science research. The activities were designed on the basis of a student-centered continuum, from more student-centered to less student-centered. “In environmental research, teachers generate research questions based on site surveys and observations, plan investigations using scientific equipment and tools, analyze data using scientific ideas, and communicate findings and processes through the creation of authentic products (i.e., original written reports and PowerPoint presentations). In field studies and investigative laboratories teachers engage in scientifically-oriented questions and give priority to evidence, but the procedures and equipment used is less student centered. In both activities, teachers formulate their own explanations based on data and guidance from identified resources.” (p. 477)
Outcomes	a) Situating teachers as learners and not as information gathers has proven effective for the development of teachers’ inquiry learning, and specifically their understanding about inquiry and skills for inquiry teaching. b) The ENVISION professional development model impacted on teachers' practice, as evidence indicates that their pedagogical approach was more consistent with the student-centred inquiry orientation (e.g., student-generated research questions, field studies, investigative laboratories). c) It was found that an increase in teachers' understanding of inquiry served as a prerequisite for changing their inquiry-based teaching. Changes of their practice were also affected by other factors, like time management issues, curricular coverage concerns, perceived instructional support and structure (control) problems, and transportation and equipment expenses.

<table>
<tr><td>Reference</td><td>Shepardson, D. P., & Harbor, J. (2004). ENVISION: the effectiveness of a dual-level professional development model for changing teacher practice. Environmental Education Research, 10(4), 471-492.</td></tr>
<tr><td colspan="2">3. A dynamic model of teacher learning</td></tr>
<tr><td>Model or Framework</td><td>A dynamic model of teacher learning was developed for the purposes of this study that illustrates variables and their relations that affect and guide teachers' learning (see Figure below).

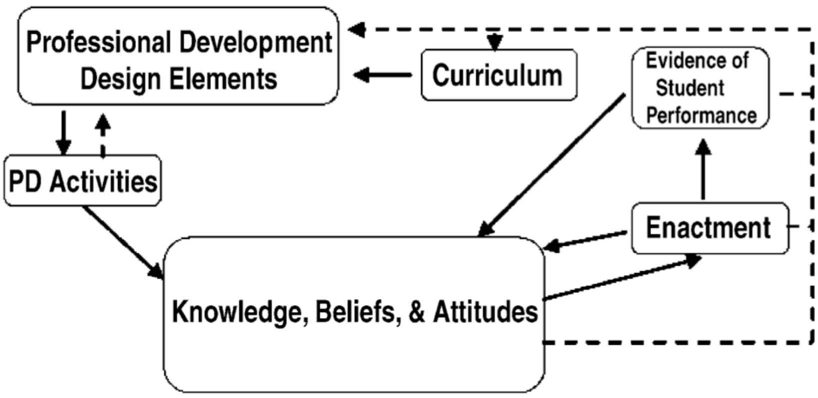


Fig. 1. Model of teacher learning.

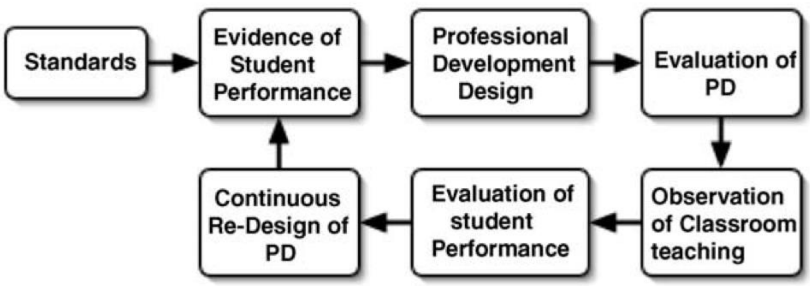
(p. 645)</td></tr>
<tr><td>Aims</td><td>"To present evidence for the value of an approach to studying professional development that takes explicit account of student learning, which is often the sole measurement upon which the success of systemic reform is judged" (p. 644)</td></tr>
<tr><td>Outline of the professional development course (PDC)</td><td>

Fig. 2. Iterative model for the evaluation of professional development.

(p. 648)</td></tr>
<tr><td>Outcomes</td><td>The design approach that was followed for the professional development course enabled the making of evidence-based and substantial improvements in both teacher learning and subsequent student</td></tr>
</table>

	performance. The identification of student difficulties in particular areas of the curriculum enabled researchers to "analyze their existing professional development and hypothesize changes that would better help teachers teach to these difficulties. Subsequent analysis of the impact of these changes indicated that the workshop pre-design had a positive impact on teachers' knowledge and beliefs about their teaching, and also on their classroom enactment. These changed teacher knowledge and beliefs translated into improved student performance on posttest evaluations of the curriculum enactment." (p. 655)
Reference	Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and teacher education*, *19*(6), 643-658.
4. A 7-step plan	
Model or Framework	A 7-step plan: "1. identify a learning bottleneck, 2. define the basic learning tasks, 3. model these tasks to your students, 4. motivate your students, 5. create practice opportunities for your students, 6. assess student learning, and 7. share what you have learned with other teachers." (p. 190)
Aims	To examine the impact of a 2-week summer research institute (SRI) on teachers' a) beliefs about teaching science through inquiry, b) change of conceptions about inquiry before, during, and after their participation to the institute, and c) lesson design capabilities.
Outline of the professional development course (PDC)	The SRI entailed two sessions. 1. A 4-hour morning inquiry workshop: a) Teachers used the 7-step plan to solve a student-learning bottleneck that they identified from their classrooms and created a lesson plan around this topic, b) Tteachers presented their proposed bottleneck lessons and received feedback from the rest of the participants. 2. A two week afternoon laboratory experience: a) Teachers were engaged in science inquiry activities in the lab as research participants and were asked to reflect on how the gained inquiry experience can be translated into science instruction in their classrooms,

	b) teachers received daily readings and homework assignments on topics that relate to inquiry teaching and learning.
Outcomes	a) Teachers reported increased confidence in incorporating inquiry activities within their practices without making major adjustments in planning and implementing their science lessons, b) teachers were benefited from the 7-step plan, as it enabled them to concentrate on learning from the perspective of the student. It also served as a means to facilitate the exchange of teaching and learning experiences with other teachers, c) teachers struggled to incorporate into their lesson plans strategies that were provided during the course, since they performed minor changes into their planned instruction. This difficulty can be attributed to the fact that teachers did not have the opportunity to try the new strategies in their classrooms and hence they felt safe to adhere to the strategies they had previously worked with, d) the activities that relate to modeling students' thinking during instruction were very scarce, since teachers chose to design more science content oriented activities in their lesson plans. Also, evidence from some teachers who claimed to have incorporated modeling students' thinking activities indicates that teachers misunderstood what this type of activity entails, since their activities pointed to telling of information instead of modeling students' thinking, e) teachers' engagement with authentic inquiry activities at the lab helped them to remember how their students feel during their exposition to new science content, and thus this learning opportunity triggered the need for designing scaffolds for their students that would facilitate their engagement with new science content.
Reference	Lotter, C., Harwood, W. S., & Bonner, J. J. (2006). Overcoming a learning bottleneck: Inquiry professional development for secondary science teachers. Journal of Science Teacher Education, 17(3), 185-216.

Table 3. Illustration of evidence to document how the critical features of effective inquiry suggested by Capps et al. (2012) were addressed in the design and implementation of the PD program

FEATURES		**How critical features of effective inquiry were addressed in the PD program of the study?**	**Frequency of occurrence in the 17 papers reviewed by Capps et al.**
STRUCTURAL FEATURES	TOTAL TIME	10 weeks – in-course (*teachers as learners and as thinkers*): 6 weeks: 12 x 1,5 hour sessions; beyond-course (*teachers as reflective practitioners*): 4 weeks: 8-10 2 hour meetings with their pupils	From 1 to 6 weeks
	EXTENDED SUPPORT	During Phase 3 (*teachers as reflective practitioners*), the teachers received feedback on their science fair project proposals by the instructors of the course. They also met with the instructors once a week on a volunteer basis to pose questions, discuss problems encountered during the meetings with their pupils, and get support on their future steps. The support received was also extended and enhanced via online communication; a social network page was created to offer teachers the opportunity to exchange ideas with their peers, share learning experiences and lessons learned from the meetings with their pupils, and also to receive feedback on their lesson plans and curriculum materials from the science teachers of the local school that their pupils came from.	13 out of 17

STRUCTURAL FEATURES	AUTHENTIC EXPERIENCE	During Phase 1 (*teachers as learners*), the teachers were engaged with a curriculum developed for the purposes of this course titled "Boiling and Peeling Eggs" and they were prompted to answer "How to make perfect hard boiled eggs that are ease to peel?" Specifically, the teachers (working in groups of 4) defined the problem that merited solution, identified variables that might affect the boiling and peeling of eggs, formulated investigative questions and hypotheses, designed and performed valid experiments to answer their questions and test their hypotheses, collected, analyzed, and interpreted data derived from their experiments, draw conclusions from the data and represented their findings in posters to communicate with the rest of their peers. They neither received lecturing on what is inquiry and how it is performed, nor were given ready-made experiments to follow in answering their questions. Instead, they worked in the science lab for an extended amount of time aiming to produce reliable knowledge on the topic of boiling and peeling eggs that could not be found in books, the internet, etc.	5 out of 17
CORE FEATURES	COHERENCE	Inquiry learning is manifested in the national curriculum of the country and the science textbooks units are considered to have been developed on the tenets of the inquiry approach. Thus, the compatibility and coherence of the aims and content of the course with the national curriculum was believed to facilitate and support teachers' teaching practice when entering the school for the purposes of their school practicum the following academic year.	all 17
	DEVELOPED LESSONS	During Phase 3 (*teachers as reflective practitioners*), the teachers were asked to developed lesson plans and curriculum materials that would use in engaging a pupil in inquiry activities for the purposes of the Science Fair project. In developing their lesson plans, the teachers formulated learning objectives and designed activities that were aligned with the principles of inquiry learning (e.g., pupils would learn how to formulate investigative questions, test hypotheses, develop and apply the control of variables skill, design and perform controlled experiments, make inferences from the data collected, use evidence to develop explanations, etc).	7 out of 17

CORE FEATURES	MODELED INQUIRY	The participating teachers (working in groups of 4) were assigned to the role of *learners* during Phase 1 of the course and followed the specially designed curriculum to complete activities and evaluation tasks in an attempt to learn first-hand how inquiry learning looks like in the curriculum. The teachers discussed the progress of their work with the course instructors during "check-out points" placed in specific stages of the curriculum. The instructors aimed to engage teachers in *semi-socratic* dialogues during the check-out points, instead of merely answering questions or providing the correct answers to the activities of the curriculum. Both the format of the curriculum, the structure of the course, and the role of the instructors aimed to help teachers in visualising how inquiry approach looks like and thus it was anticipated that they would appear more ready and confident in their own field of practice for scaffolding their pupils' learning pathways while involved in inquiry activities.	16 out of 17
	REFLECT	During Phase 1 (teachers as learners), the teachers were asked to keep reflective diaries to record their evolved understandings of inquiry, the questions and problems that emerged during working with the curriculum to answer the investigative questions they formulated, and their impressions from the course. Also, during positioning teachers as thinkers (Phase 2) they were asked to reflect on the curriculum they were engaged in the previous stage as learners from the lens of its pedagogical rationale, and discuss how inquiry skills and knowledge were fostered within specific learning activities.	15 out of 17
	TRANSFERENCE	Teachers adapted the format and structure of the curriculum they were engaged with during Phase 1 in designing their own curriculum that would use during engaging an elementary school pupil in inquiry activities for the purposes of the Science Fair. During designing their curriculum materials, they received feedback from the instructors on certain aspects of their work, which was proven beneficiary in transferring the PD materials and experiences in their own field of practice.	15 out of 17

CORE FEATURES	CONTENT KNOWLEDGE	The course not only focused in engaging teachers in inquiry activities, but also on helping teachers develop specific content knowledge, including understanding of certain aspects of nature of science, nature of scientific inquiry, and science concepts that related to the context of the curriculum (e.g., boiling, heat and temperature, egg protein denaturation, etc). Additionally, the course gave emphasis in promoting teachers' development of inquiry skills like control of variables, design of controlled experiments, data interpretation and inference drawing, etc.	11 out of 17

Appendix 8.10 Web-based materials for Teacher Educators/Researchers: How/when/why to prompt teachers to reflect on their evolved understandings of inquiry and inquiry approach?

Teachers, and in general educators, develop practices of teaching with which they feel comfortable and confident. When they mature it is usually difficult to change, or they feel insecure to adopt an innovative methodology such as inquiry-based teaching. However, when asked in surveys, the majority of teachers express the willingness to adopt new methods and models of science teaching, that have proven effectiveness and that lead their pupils to better results in terms of concept and content understanding. A required condition is that they are thoroughly trained in practicing these new methods before applying them to their everyday classroom teaching.

In this context dedicated workshops with a well-balanced mix of advanced, experienced, and non-experienced teachers help them to practice by following examples, develop further and reflect on their best-practices and understanding on various subjects such as: what is inquiry process, what is inquiry approach and science teaching, what are the main advantages of this method, which are the common mistakes to avoid, etc. These workshops, often called in literature, "practice reflection workshops", can be offered in parallel or within the framework of professional development programs and in a regular basis so that more teachers can be involved. They can be grouped in terms of subject and content or in terms of level of difficulty and prerequisites. In general three series of workshops are proposed, that follow the general training framework and approach of the "Ark of Inquiry" project, which as already has been described in other sections involves the participants in three distinct modes i.e. as learners, as thinkers and finally as reflective practitioners.

In the initial phase practice reflection workshops are suggested to take place soon after (within a couple of months) a training event about inquiry-based science teaching offered within the Ark of Inquiry project. In this series participant teachers mainly reflect on the understanding they acquired during training and will act as being learners themselves ("teachers as learners") or in other words experience, practice and reflect on inquiry learning from the learner's perspective. One of the main objectives of these workshops is also to raise awareness and clarify possible misconceptions about inquiry, its main steps, their importance etc. They will also motivate participant teachers to start developing their own or adopt existing inquiry-based lesson plans in collaboration with their fellow teachers. A workshop of this type may consist of two main sessions. The first session, about 1-1.5 hrs long, will have presentations and short reminders about what inquiry is, which are the main steps etc. This session will open the discussion among the teachers so that they reflect on their own understanding but also compare with each other's approaches. The second session, about 1-1.5 hrs long, can be a model practice or group work on a given lesson plan based on inquiry. In this session teachers are asked to identify and discuss strong and weak points, main advantages and barriers, do clarifications and develop further their understanding and confidence. At the end or during the sessions of the workshop questionnaires are distributed to all participants for feedback collection on mainly two topics, on teachers understanding and opinions on inquiry learning and inquiry based science education, and on the quality of the content presented during the workshop and its overall structure. The workshop finishes with round table wrap-up discussion. Below is a proposed agenda for a workshop of this type.

Example agenda of a "teachers as inquiry learners" practice reflection workshop of the Ark of Inquiry:

Time	Session description
9:00 - 10:00	Introduction and welcome (5 min) Presentation: what is inquiry and which are the main steps. Presentation of an example educational scenario based on inquiry
10:00 - 10:30	Discussion and reflection
10:30 - 10:45	Break
10:45 - 11:45	Hands-on practice on a proposed activity or group work to develop one on given theme
11:45 - 12:15	Discussion and reflection
12:15 - 12:45	Wrap-up presentation or round table wrap-up discussion and conclusions

The "Ark of Inquiry" training program for teachers incorporates a gradual structure to facilitate change of attitude in parallel to knowledge development. Within this structure, teachers reflect on what they know already about inquiry, how they learned it or practiced it, and what are the achieved results and benefits for the pupils. Teachers are better able to understand essential aspects of inquiry learning and teaching by discussing and thinking about inquiry instruction, and also share their experiences with other teachers. They basically act as critical thinkers, questioning constructively the pros and cons of inquiry learning methods in everyday science classrooms. They furthermore discuss or propose how certain learning activities may facilitate pupils' inquiry skills and knowledge. These discussions and reflections of teachers as thinkers can be facilitated in dedicated practice reflection workshops. These practice reflection workshops can be organised for teachers that they have developed their own inquiry lessons or feel confident to adopt an existing one and practice it in their science classroom. More experienced teachers that have already practiced inquiry approach can be invited in these workshops to act as instructors or to present their best-practices. In these workshops participants discuss in deep and reflect on their developed practices. They discuss on difficulties they foresee or expect or have experienced and propose work-arounds or methods to avoid them. The objective of the workshops of this type is not only to motivate more teachers and newcomers to adopt a new methodology or reflect on it and act as critical thinkers themselves but also to provide them with practical answers and assistance on how to break any last barriers or fears they have before an actual inquiry activity can be implemented in their school. As a consequence the participation of more experienced teachers in these workshops is crucial to act as role models or facilitators. A workshop of this type is practically a follow-up of a "teachers as learners" practice reflection workshop and can be organised soon after that on participants request and convenience. It may consist of two main sessions. The first session, about 1-1.5 hrs long, consists of presentations of selected best-practices or developed inquiry activities on which all participants will reflect on later. The second session, about 1-1.5 hrs long, will mainly focus on participant's discussions about difficulties, identified or expected problematic areas, and proposed solutions. The workshop finishes with round table wrap-up discussion or presentation. At the end or during the sessions of the workshop questionnaires are distributed to all participants for feedback collection. If time permits the organisers may schedule at the end of the workshop an interviewing session with volunteer participants or selected teachers to thoroughly discuss and express their thinking on inquiry learning in an open and critical way. Below is a proposed agenda for a workshop of this type.

Example agenda of a "teachers as critical thinkers" practice reflection workshop of the Ark of Inquiry:

Time	Session description
9:00 - 10:00	Introduction and welcome (5 min) Presentations of selected educational scenarios based on inquiry and best-practices at various levels of difficulty
10:00 - 10:30	Discussion and reflection
10:30 - 10:45	Break
10:45 - 12:15	Discussion on difficulties, identified or expected problematic areas, and proposed solutions/improvements
12:15 - 12:30	Wrap-up

Final practice reflection workshops can be organised in the last phase of implementation of the project when the participant teachers have already finished the "Ark of Inquiry" proposed training and they have actually practiced teaching by inquiry in their science classrooms. The teachers have now passed from the states of "teachers as learners" and "teachers as thinkers" and are reflective practitioners that have developed the required skills and confidence to assess, evaluate, easily adopt, but also adapt and redesign and develop authentic inquiry learning activities. In these final practice reflection workshops all participant teachers have practiced and implemented inquiry activities in their classrooms. They are now in a position to assess their achieved results and so to reflect on the efficacy of the inquiry method. The main focus is to discuss outcomes and propose improvements on the approach in a holistic way, the training offered or needed, possible prerequisites or further training material and content etc. A workshop of this type can have a more official character and be part of a closing conference at the end of the project. It may consist of a session of invited speakers followed by a session where best case scenarios teachers present their work and outcomes. The closing session will focus on proposed next-steps and improvements. At the end or during the sessions of the workshop questionnaires are distributed to all participants for feedback collection on mainly three topics, first on teachers' assessment and evaluation of achieved results, second on re-collection of feedback on understanding and opinions on inquiry learning and inquiry based science education, and third on the quality, overall structure and effectiveness of the training and reflection program of the "Ark of Inquiry" approach. Below is a proposed agenda for a workshop of this type.

Example agenda of a final "teachers as practitioners" reflection workshop of the Ark of Inquiry:

Time	Session description
9:00 - 10:30	Introduction and welcome (5 min) Presentations of success stories, best-practices and best outcomes
10:30 - 10:45	Break
10:45 - 12:15	Discussion and reflection on outcomes achieved, methodologies practiced, experiences, next-steps, proposed future improvements
12:15 - 12:30	Closing/Wrap-up

Appendix 8.11 Web-based materials for Teacher Educators/Researchers: A showcase of instruments to capture teachers' initial, evolving and final understandings of various underpinnings that relate to inquiry and teaching science as inquiry

This is a collection of various web-based materials, which were described in literature or developed in various European projects related to STEM teaching and learning. We suggest that teacher trainers or teachers choose and adapt the materials best fit for their purpose based on the description of the specific tool and the related references. This material provides a brief overview of the rationale and gives ideas on how and when to use the tool.

1. Online Questionnaires

1.1. Pedagogical Knowledge in Inquiry Based Teaching

Rationale: This 5-point Likert-scale questionnaire provides information about teachers' self-efficacy, pedagogical process knowledge and the professional learning process. The questionnaire focuses on elements needed to bridge pedagogical content knowledge and teaching practice in order to analyse the effects and outcomes of a professional development course. (Lee, 2011)

When to use: it is best to use either before or prior to and after a professional learning course, for formative or summative assessment.

How to use: the simplest and most practical way of using this questionnaire is to prepare an online version at any convenient and suitable platform.

What type of data it can collect: using this tool one can establish the learning outcomes (in terms of pedagogical process knowledge) of a teacher training course. If a modified version of questions 1- (e.g.: I feel confident about teaching inquiry-based science, I am familiar with scientific concepts of topics, etc.) are used only before the teacher training, data collected here can help trainers to design a learning program better tailored to participants' needs (by adapting the standard program focusing on empowerment and targeted support).

The questionnaire:

Please indicate your choice on the scale. 1= strongly disagree; 5= strongly agree

	1	2	3	4	5
1. I feel more confident about teaching inquiry-based science.					
2. I have become more familiar with scientific concepts of this topic.					
3. I find it more difficult to teach inquiry-based science.					
4. I can determine pupils' incorrect concepts of the topic more easily.					
5. I have become more aware of pupils' incorrect concepts of scientific knowledge.					
6. Through the workshop, I came to realise the importance of understanding pupils' prior concepts when teaching science subjects.					
7. I am better able to design inquiry activities to trigger pupils' motivation to explore natural phenomena.					
8. By guiding pupils in scientific inquiry activities, I can clarify their misconceptions more easily.					
9. I can teach the same topic better in future by adopting the same teaching approach.					
10. Thanks to the workshop, I am more confident in my ability to apply inquiry approach to other topics.					
11. I have a better understanding of the inquiry approach (learning and teaching) on reflection.					
12. I can answer pupils' questions about this topic more easily.					
13. I have learned how to design, organise, and use inquiry approach materials and equipment.					
14. I need more instructions to independently design and apply inquiry approach.					
15. Collaborating with tutors has extended my professional pedagogical knowledge of inquiry-based science learning and teaching.					
16. I know more about pupils' scientific thinking and their limitations.					

1.2. Inquiry Beliefs and Practices Questionnaire

Rationale: this 5-point Likert scale questionnaire reports on teachers' beliefs on their own inquiry approach practice, namely how elements of inquiry (such as asking questions about the natural word, planning investigations and collecting, organising and analysing relevant data, thinking critically and logically about relationships between evidence and explanations, and using observational evidence and current scientific knowledge for construction of, evaluation and communication about explanations) are self-reportedly present in their perception of own professional practice, and what type of inquiry activities (according to the inquiry continuum from guided to open or full inquiry) they self-reportedly profess (Jeanpierre, 2006).

When to use: it can be used for formative and summative assessment

How to use: the simplest and most practical way of using this questionnaire is to prepare an online version at any convenient and suitable platform

What type of data it can collect: this tool collects evidence of self-perception, self-reflection, and through these, visions of teachers about their own practice of inquiry based science teaching

The questionnaire:

Please use the rating which best describes your inquiry teaching and learning beliefs. 5= almost always; 4= often; 3= sometimes; 2= seldom; 1= almost never

	5	4	3	2	1
1. I am a facilitator of pupils' learning.					
2. I welcome pupils' questions.					
3. I encourage pupils to seek answers to their own questions.					
4. I ask pupils what they are interested in learning.					
5. I use pupils' interests as a guide when constructing my lessons.					
6. I use discrepant events to motivate pupils.					
7. I do not depend on the textbook.					
8. I focus on pupils' understanding of science concepts.					
9. I have pupils develop their own hypotheses.					
10. I have pupils design their own experiments.					
11. I have pupils analyse data based on their own research					
12. I have pupils interpret their data based on their research evidence.					
13. I have pupils read the research of others in the science community which relates to their own research prior to deciding on a research question.					
14. I have pupils communicate their research results to their peers.					
15. I have pupils share their research results in a formal out-of-class setting (e.g. science fair, competition, etc.)					
16. I provide pupils with science inquiry experiences that are balanced between developing their research skills and concept understanding.					

1.3. Beliefs About Science and School Science Questionnaire (BASSSQ)

Rationale: this questionnaire is intended to *"serve to identify teachers' beliefs about the nature of science, in order to provide greater insight into ways in which those views affect teaching practices"* (Aldridge, Taylor & Chen, 1997., p.1.). Besides, it gives insight to teachers' views on school science. Additionally, "*BASSSQ was designed to provide a heuristic device that teacher-researchers can use as a means of reflecting on, and improving, their own teaching practices"* (ibid.p.2.).

When to use: it is best to use either before or prior to and after a professional learning course

How to use: the simplest and most practical way of using this questionnaire is to prepare an online version at any convenient and suitable platform

What type of data it can collect: using this tool one can establish the learning outcomes (in terms of pedagogical process knowledge) of a teacher training course; if used only before the teacher training, data collected here can help trainers to design a learning program better tailored to participants' needs (by adapting the standard program focusing on empowerment and targeted support. This tool is *"concerned primarily with the beliefs teachers hold about the nature of science and science teaching"* (ibid. p.2), placing it in a two-dimension model of the continuum from objectivistic to post-modern view on the nature of science.

Your Views About What Occurs in Science
Please indicate how often, in your opinion, each practice **occurs in science.**

PROCESS OF SCIENTIFIC INQUIRY	Almost Never	Seldom	Sometimes	Often	Almost Always
1.* Scientific observations depend on what scientists set out to find.	1	2	3	4	5
2. Scientific inquiry involves challenging other scientists' ideas.	1	2	3	4	5
3. Scientific observations are affected by scientists' values and beliefs.	1	2	3	4	5
4.* Scientific inquiry involves thinking critically about one's	1	2	3	4	5
5. Intuition plays a role in scientific inquiry.	1	2	3	4	5
6. When making observations, scientists eliminate their beliefs and values.	1	2	3	4	5
7. Scientific observations are guided by theories.	1	2	3	4	5
8. Scientific inquiry starts with observations of nature.	1	2	3	4	5
9. Scientific investigation follows the scientific method.	1	2	3	4	5
10. Scientific ideas come from both scientific and non-scientific sources.	1	2	3	4	5
11. Scientific knowledge gives a true account of the natural world.	1	2	3	4	5
12. Scientific knowledge is tentative.	1	2	3	4	5
13. Scientific knowledge is relative to the social context in which it is generated.	1	2	3	4	5
14.* Scientific knowledge can be proven.	1	2	3	4	5
15. The evaluation of scientific knowledge varies with changes in situations.	1	2	3	4	5
16. The accuracy of current scientific knowledge is beyond question.	1	2	3	4	5
17.* Currently accepted scientific knowledge will be modified in the future.	1	2	3	4	5
18. Scientific knowledge is influenced by cultural and social attitudes.	1	2	3	4	5
19. Scientific knowledge is free of human perspectives.	1	2	3	4	5
20. Scientific knowledge is influenced by myths.	1	2	3	4	5

Your Views About What Should Occur In School Science

Please indicate how often, in your opinion, each practice **should occur in school science**.

PROCESS OF SCHOOL SCIENCE INQUIRY	Almost Never	Seldom	Sometimes	Often	Almost Always
21. In science classes, investigations should enable pupils to explore their own ideas.	1	2	3	4	5
22. In science classes, pupils should work collaboratively.	1	2	3	4	5
23. In science classes, pupils should discuss ideas with others.	1	2	3	4	5
24. In science classes, pupils should think creatively.	1	2	3	4	5
25. In science classes, pupils should explore different methods of investigation.	1	2	3	4	5
26. Pupils should view science as a problem-solving exercise.	1	2	3	4	5
27.* In science classes, inquiry learning should start with observation.	1	2	3	4	5
28.* In science classes, pupils should apply the scientific method.	1	2	3	4	5
29. Pupils should enjoy themselves during science experiments.	1	2	3	4	5
30.* Pupils should be taught that there is a distinction between theory and observation.	1	2	3	4	5
31. In science classes, pupils should consider ethical issues related to scientific investigation.	1	2	3	4	5
32. In school science, pupils should be critical of accepted theories.	1	2	3	4	5
33. In school science, pupils should view scientific knowledge as tentative.	1	2	3	4	5
34. In school science, pupil understanding should be influenced by their existing knowledge.	1	2	3	4	5
35. In school science, pupils should examine the history of accepted scientific knowledge.	1	2	3	4	5
36. In school science, pupils should learn that more than one theory can account for a given set of data.	1	2	3	4	5
37. In school science, pupils should learn about competing theories.	1	2	3	4	5
38.* In school science, pupils should be taught that accepted scientific knowledge will be modified in the future.	1	2	3	4	5
39. In school science, pupils should examine how society influences what counts as scientific knowledge.	1	2	3	4	5
40.* In school science, pupils should consider social issues related to accepted scientific knowledge.	1	2	3	4	5
41. In school science, pupils should be taught that scientific knowledge is objective and therefore free of human values.	1	2	3	4	5

*Items omitted during analysis

Underlined items reflect a more objectivist view and were therefore scored in reverse.

1.4. Student Understanding of Science and Scientific Inquiry (SUSI) Questionnaire

Rationale: this questionnaire contains open-ended and Likert-scale items as well, and is intended to *"assess students' understanding about how scientific knowledge develops"* and to conduct cross-cultural comparison (Liang et al, 2006).

When to use: it is suitable for formative and summative assessment, also for pre/post survey in training courses (Macklin, Adams, 2006)

How to use: the simplest and most practical way of using this questionnaire is to prepare an online version at any convenient and suitable platform

What type of data it can collect: using this tool one can establish the learning outcomes (in terms of pedagogical process knowledge) of a teacher training course; if used only before the teacher training, data collected here can help trainers to design a learning program better tailored to participants' needs (by adapting the standard program focusing on empowerment and targeted support) or it can also be used to compare cultural differences (for which demographic data including educational and sociocultural background, gender, teaching experience, teaching environment, etc. is necessary).

Student Understanding of Scientific Inquiry Questionnaire

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate letters to the right of each statement.

SD = Strongly Disagree; D = Disagree more than agree; U = Uncertain or not sure;
A = Agree more than disagree; SA = Strongly agree

1. Observations and Inferences					
A. Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	SD	D	U	A	SA
B. Scientists' observations of the same event will be the same because scientists are objective.	SD	D	U	A	SA
C. Scientists' observations of the same event will be the same because observations are facts.	SD	D	U	A	SA
D. Scientists may make different interpretations based on the same observations.	SD	D	U	A	SA
With examples, explain why you think scientist's observations and interpretations are the same OR different.					
2. Nature of Scientific Theories					
A. Scientific theories are subject to on-going testing and revision.	SD	D	U	A	SA
B. Scientific theories	SD	D	U	A	SA
C. Scientific theories may be changed because scientists reinterpret existing observation.	SD	D	U	A	SA
D. Scientific theories based on accurate experimentation will not be changed.	SD	D	U	A	SA
With examples, explain why you think scientific theories change OR do not change over time.					
3. Scientific Laws versus Theories					
A. Scientific theories exist in the natural world and are uncovered through scientific investigations.	SD	D	U	A	SA
B. Unlike theories, scientific laws are not subject to change.	SD	D	U	A	SA
C. Scientific laws are theories that have been proven.	SD	D	U	A	SA
D. Scientific theories explain scientific laws.	SD	D	U	A	SA
With examples, explain the difference between scientific theories and scientific laws.					

4. Social and Cultural Influence on Science					
A. Scientific research is not influenced by society and culture because scientists are trained to conduct "pure", unbiased studies.	SD	D	U	A	SA
B. Cultural values and expectations determine what science is conducted and accepted.	SD	D	U	A	SA
C. Cultural values and expectations determine how science is conducted and accepted.	SD	D	U	A	SA
D. All cultures conduct scientific research the same way because science is universal and independent of society and culture.	SD	D	U	A	SA
With examples, explain how society and culture affect OR do not affect scientific research.					
5. Imagination and Creativity in Scientific Investigations					
A. Scientists use their imagination and creativity when they collect data.	SD	D	U	A	SA
B. Scientists use their imagination and creativity when they analyze and interpret data.	SD	D	U	A	SA
C. Scientists do not use their imagination and creativity because these conflict with their logical reasoning.	SD	D	U	A	SA
D. Scientists do not use their imagination and creativity because these can interfere with objectivity.	SD	D	U	A	SA
With examples, explain why scientists use OR do not use imagination and creativity.					
6. Scientific Investigation					
A. Scientists use a variety of methods to produce fruitful results	SD	D	U	A	SA
B. Scientists follow the same step-by-step scientific method.	SD	D	U	A	SA
C. When scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
D. Experiments are not the only means used in the development of scientific knowledge.	SD	D	U	A	SA
With examples, explain whether scientists follow a single, universal scientific method OR use different methods.					

Evaluation:

The following table (Taxonomy of Views about Nature of Scientific Knowledge (NSTA, 2000; AAAS, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), quoted by Macklin and Adams, 2006) contains information about what aspects specific items refer to in the questionnaire. Items with a (+) denote a correct score as either "Strongly Agree or Agree"; items with (-) denote a correct score as either "Strongly Disagree or Disagree".

Aspect	Explanation/Description	Items
Tentativeness	Scientific knowledge is simultaneously reliable and tentative. Having confidence in scientific knowledge is reasonable while realising that such knowledge may be abandoned or modified in light of new evidence or reconceptualisation of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes.	1A(-); 1E (+); 1G(-); 2A (+); 2G(-); 5A (+); 5B (+); 5C(+); 5D (-);
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world. Science aims to be testable.	1F(+); 5A (+); 5B(+)
Observations and inferences	Science is based on both observations and inferences. Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extensions of those senses) and about which observers can reach consensus with relative ease. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.	2B(+); 9A(+); 9B(+); 9C(-); 9D(-); 9E(+);
Subjectivity/objectivity	Science aims to be objective and precise, but subjectivity in science is unavoidable. The development of questions, investigations, and interpretations of data are to some extent influenced by the existing state of scientific knowledge and the researcher's personal factors and social background.	2A (+); 2B(+); 2C(+); 2D(+); 2E(+); 2F(+); 2G (-);
Creativity/rationality	Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on	1I (+); 4A(+); 4B(+); 4C(+);

	observations and inferences of the natural world. Scientists use their imagination and creativity throughout their scientific investigations.	4D(+); 4E(-); 4F(-); 10D(+);
Social and cultural embeddedness	Science is part of social and cultural traditions. People from all culture contribute to science. Science requires accurate record keeping and peer review and aims to be replicable. As a human endeavour, science is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.	1D(+); 1H (+); 3A (+); 3B(+); 3C(+); 3D(-); 3E(-); 3F(-);
Scientific theories and laws	Both scientific laws and theories are subject to change. Scientific laws describe generalised relationships, observed or perceived, of natural phenomena under certain conditions. Scientific theories are inferred explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories.	6A (-); 7A(-); 7B(-); 8A (-); 8B (-); 8C(+); 8D(-); 8E(+)
Multiple methods of scientific investigations	There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is gained in a variety of ways including observation, analysis, speculation, library investigation and experimentation.	1C(-); 3D(-); 10A(-); 10B (-);10E(+); 10F(-)

1.5. Classroom case studies assessment tool

Rationale: this tool provides questions for reflection on specific learning situations, and was originally designed as an activity for teachers to better understand the main principles of inquiry-based biology teaching (Biological Sciences Curriculum Study, 2006)

When to use: it is best to use during a professional learning course

How to use: it can be part of an activity, or a digital learning material, but may work as a paper-and-pencil instrument too

What type of data it can collect: it refers to teachers' perceptions of learning environments

The activity

Instructions:

1. *Read the six scenarios.*
2. *Review the summary of observations in table and answer the questions.*

Classroom Case Studies. Teaching Science as Inquiry

A teacher wanted to see inquiry in action, so she visited six different class-rooms. Her considerations included the content of lessons, the teaching strategies, the student activities, and the outcomes—what students learned. During five days in each classroom, she made the following observations.

Classroom #1

The students engaged in an investigation initiated by significant student interest. A student asked what happened to the water in a watering can. The can was al-most full on Friday and almost empty on Monday. One student proposed that Willie the pet hamster left his cage at night and drank the water. The teacher encouraged the students to find a way to test this idea. The students devised a test in which they covered the water so Willie could not drink it. Over several days, they observed that the water level did not drop. The teacher then challenged the students to think about other explanations. The students' questions resulted in a series of full investigations about the disappearance of water from the container. The teacher emphasised strategies such as asking students to consider alternative explanations, using evidence to form their explanations, and designing simple investigations to test an explanation. The science teacher never did explain evaporation and related concepts.

Classroom #2

Students investigated batteries and bulbs to learn about electricity. The teacher gave teams of students a battery, a bulb, and a piece of wire. To begin, the teacher told the students to use the materials and to "light the bulb." In time, the student teams lit the bulb and made observations about the arrangement of the battery, the wire, and the bulb.

The teacher then provided other batteries, wires, small buzzers, and other materials and asked the students to explore different arrangements and see what they could learn. As the students continued their activity, the teacher pointed out certain results of their battery, bulb, wire, and buzzer systems. After several days of exploration with the materials, the teacher introduced the ideas that (1) electricity in circuits can produce light, heat, sound, and magnetic effects; (2) electrical circuits require a complete loop through which an electrical current can pass; and (3) electrical circuits provide a means of transferring electrical energy when heat, light, and sound are produced. In the end, students learned some basic ideas about electricity.

Classroom #3

In this classroom, the students selected from among several short stories that provided discussions of scientists and their work. Stories included Louis Pasteur, Marie Curie, Jonas Salk, and Barbara McClintock. Over a three-week period, every student read one of the stories as homework. Then, in groups of three, all student groups discussed and answered the same questions: "What questions did the scientist ask?" "What type of investigations did the scientist conduct?" "What instruments and equipment did the scientist use?" "How did the scientist use observations to answer his or her questions?" After reading the stories and completing the discussion questions, the teacher had the groups prepare oral reports on the topic "how scientists do their investigations."

Classroom #4

The students were engaged in an investigation initiated by significant student interest. A student asked why the plants on the windowsill all seemed to be facing the window. The plants had been pointing to-ward the classroom on Friday, and by Monday, all the leaves and flowers were facing away from the class-room. One student proposed that the teacher had turned all the plants around on Monday morning. The teacher indicated that this had not been done and encouraged the students to ask other questions that they could test. Eventually, the students decided to find out if the plants could follow the light. The students devised a test in which they covered half the plants for several days and turned the other half back toward the class-room. Over several days, they observed that the uncovered plants turned back to the window, but the covered plants did not. The teacher then challenged the students to think about other explanations. The students' questions resulted in a series of full investigations about plant phototropism. The teacher emphasised strategies such as asking students to consider alternative explanations, using evidence to form their explanations, and de-signing simple investigations to test an explanation. The science teacher never did explain phototropism and related concepts.

Classroom #5

Students investigated fossils to learn about biological evolution. The teacher distributed two similar, but slightly different, molds with dozens of fossil brachiopods. The students measured the lengths and widths of the two populations of brachiopods. The teacher asked if the differences in length and width might represent evolutionary change. As the students responded, the teacher asked, “How do you know?” “How could you support your answer?” “What evidence would you need?” “What if the fossils were in the same rock formation?” “Are the variations in length and width just normal variations in the species?” “How would a difference in length or width help a brachiopod adapt better?” The fossil activity provided the context for students to learn about the relationships among (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) the finite supply of resources required for life, and (4) the ensuing selection by the environment for those offspring better able to survive and leave offspring. In the end, students learned about changes in the variations of characteristics in a population-biological evolution.

Classroom #6

In this science classroom, students selected from among several books that provided extended discussions of scientific work. Readings included The Double Helix, The Beak of the Finch, and A Feeling for the Organism. Over a three-week period, each student read one of the books as homework.

Then, in groups, the students discussed and answered the same questions: “What led the scientist to the investigation?” “What conceptual ideas and knowledge guided the inquiry?” “What reasons did the scientist cite for con-ducting the investigations?” “How did technology enhance the gathering and manipulation of data?” “What role did mathematics play in the inquiry?” “Was the scientific explanation logically consistent? Based in evidence? Open to sceptical review? Built on a knowledge base of other experiments?” After reading the books and completing the discussion questions, the teacher had the groups prepare oral reports on the topic “the role of inquiry in science.”

Summary of observations

Classroom	#1	#2	#3	#4	#5	#6
Content of lessons	Changing water level in an open container	Investiga-tion of electricity	Stories of scientists and their work	Movement of plants	Investiga-tion of variations in fossils	Stories of scientists and their work
Teaching strategies	Challenge students to think about proposed explanations and use evidence to support conclusions	Provide batteries, bulbs and wires and ask students to light the bulbs and explore different arrangement of materials	Provide questions to focus discussions of readings	Challenge students to think about proposed explanations and use evidence to support conclusions	Provide mold of fossils and ask questions about student measure-ments and observa-tions	Provide questions to focus discussions on readings
Student activities	Design simple but full, investigations	Get bulbs to light, buzzers to make sounds	Read and discuss stories about scientific investiga-tions	Design simple, but full, investiga-tions	Measure fossils and use data to answer questions	Read and discuss a book about scientific investigations
Student outcomes	Develop the ability to reason using logic and evidence to form an explanation	Understand some of the basic concepts of electricity	Understand scientific inquiry as it is demonstra-ted in the work of scientists	Develop the ability to reason using logic and evidence to form an explanation	Under-stand some of the basic concepts of evolution	Understand scientific inquiry as it is demonstrated in in the work of scientists

Stop and think

Steps 1 and 2 should have engaged your thinking about teaching science as inquiry. To further clarify your thinking, take a few minutes and respond to the following questions. Refer to the case studies or summary table as often as necessary. Select the best answers and provide brief explanations for your answers.

1. Which classroom scene would you cite as the best example of teaching science as inquiry?

A. 1
B. 2
C. 3
D. 4
E. 5
F. 6
G. None of the classrooms
H. All of the classrooms

2. If teaching science as inquiry is primarily interpreted to mean using laboratory experiences to learn science concepts, which classrooms were the best example?

A. 1
B. 2
C. 3
D. 4
E. 5
F. 6
G. None of the classrooms
H. All of the classrooms

3. Suppose students had numerous experiences with the same teaching strategies and student-originated activities as classrooms #1 and #4, but the questions the students pursued varied. What would you predict as the general learning outcomes for students?

A. Their thinking abilities, understanding of subject matter, and under-standing of inquiry would be higher than students who were in the other two classes.

B. Their thinking abilities, understanding of subject matter, and under-standing of inquiry would be lower than students who were in the other two classes.

C. Their thinking abilities would be higher, and understanding of subject matter and inquiry would be lower than students who were in the other two classes.

D. Their understanding of subject matter would be higher, and thinking abilities and understanding of inquiry would be lower than students in the other two classes.

E. All learning outcomes would be the same as that of the students in the other two classes.

4. Suppose the teacher continues observing the classrooms for another week. What would you recommend she look for in order to formulate an answer to the question, "What is teaching science as inquiry?"

A. What the students learned about scientific inquiry

B. What teaching strategies the teacher used

C. What science information, concepts, and principles the students learned

D. What inquiry abilities the students developed

E. What teachers should know and do to achieve the different learning goals of scientific inquiry

5. Based on the observations of these classrooms, which of the following generalizations about teaching science as inquiry would you make?

A. Overuse of one teaching strategy may constrain opportunities to learn some science subject matter.

B. There may be benefits and trade-offs of different teaching strategies and student activities.

C. The potential learning outcomes for any one sequence of lessons may be greater than the sum of the individual lessons.

D. Different learning outcomes may require different teaching strategies.

E. All of the above

6. Based on these observations, the science teacher proposes that teaching science as inquiry may have multiple meanings. Which of the following would you recommend as a next step in her investigation?

A. Explore how others have answered the question, "What is teaching science as inquiry?"

B. See how the National Science Education Standards explain science as inquiry.

C. Elaborate on the implications of teaching science as inquiry in the context of classrooms.

D. Try teaching science as inquiry in order to evaluate the approach in school science programs.

E. All of the above

1.6. Teacher inquiry levels self-check

Rationale: this tool helps practitioners understanding the different levels of inquiry proposed by a four-level model after the Herron-scale (Bell, Smetana & Binns, 2005).

When to use: it is best to use during a professional learning course or for self-check of understanding differences within the inquiry continuum.

How to use: it can be part of an activity, or a digital learning material, but may work as a paper-and-pencil instrument too.

What type of data it can collect: it refers to teachers' understanding of levels of inquiry.

1a. Students complete a Moon phase calendar by: a) cutting out photographs of the Moon in different phases, b) mounting them on a monthly calendar on the proper date, and c) labelling each of the eight major Moon phases.	**1b.** After completing a pre-assessment activity on students' knowledge of Moon phases, a student asks about the correct order of Moon phases. The teacher challenges students to determine the sequence of phases by observing the Moon and recording their observations for one month.	**1c.** The teacher begins with the question "Does the Moon rise and set at the same time every night?" Following a brief discussion of the question, the teacher demonstrates the rising and setting of the Moon for several sequential evenings using a computer simulation. The teacher then facilitates a class discussion in which the class concludes that the Moon rises and sets about 50 minutes later each evening.
2a. Students define and describe the El Nino effect by using text and images they find on the internet.	**2b.** Students go to the library to find newspaper accounts describing the impact of El Nino on the California coast. They then summarise what they find in a two-page written report.	**2c.** Students select a location in the U.S. then search the internet for monthly temperature data of this location for the most recent El Nino year. Students then compare monthly temperature data for the El Nino year to the average temperature data for the past 50 years in order to assess the impact of El Nino on that particular location.

Examples 1b, 1c, and 2c entail both a research question and data analysis and thus support inquiry learning. In Example 1b, the teacher provides the question, “What are the phases of the Moon?” Student answers to the question are based on analysis of their own Moon observations. In Example 1c, an inquiry lesson is incorporated into a teacher-led demonstration. Although the teacher presents the data using a computer simulation, students are involved as a class in analysing the virtual observations. Example 2c challenges students to answer the question, “What is El Niño’s impact on the climate at a given locality?” Students answer that question based on analysis of data collected on the internet.

1.7. Pedagogy of Science Inquiry Teaching Test (POSITT)

Rationale: this assessment tool was designed for testing pre-service teachers' pedagogical knowledge of inquiry science teaching based on sets of objective items based on realistic classroom scenarios and teaching issues encountered in practice, for use during undergraduate instruction of prospective teachers, to both assess and promote understanding of inquiry science pedagogy (Schuster et at., 2006)

When to use: it can be used for formative and summative assessment

How to use: it can be part of an activity, or a digital learning material, but may work as a paper-and-pencil instrument too

What type of data it can collect: it refers to pre-service (student)teachers' understanding of inquiry practice

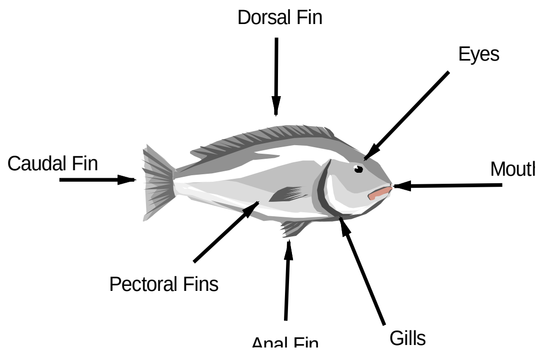
Exemplar items

Each item begins with a realistic classroom teaching vignette on a particular science topic. This is turned into a problem by asking a question about pedagogy, with a set of alternative responses to choose from. There are various possible types of items, for example an evaluation of the lesson so far, suggestions for what the teacher should do next, alternative lesson designs and approaches, ways of handling questions or occurrences, etc.

EXAMPLE 1: Starting to teach about form and function Fish

Mr. Lowe is a 3rd grade teacher. Two of his eventual objectives are for students to learn at a simple level about the relationship between form and function.

He begins a specific lesson on fish by showing an overhead transparency of a fish, naming several parts, and labelling them as shown.



Which of the following is the best evaluation of the lesson so far?

A. This is a good lesson so far, because the teacher is clearly and systematically introducing the vocabulary that the children will need for further studies of fish.
B. This is a good lesson so far, because by learning the names of the fish parts, the students are more engaged and will ask appropriate questions about their function.

C. This lesson is not off to a good start, because it begins with the teacher giving the children information about fish, before any attempt to develop a sense of questioning or investigation on the part of the students.
D. The lesson is not off to a good start, simply because it begins with the teacher doing the talking, which is never a good idea.
E. This lesson is not off to a good start, because the students are not doing anything "hands-on." There should always be real fish for students to observe, so they would connect the lesson to the real world.

Comments on Example Item 1

Of the options, “C” is the desired response according to the inquiry pedagogy criteria. “C” suggests the teacher should engage students through questioning about what they notice and know about fish. The teacher should guide students to describe the various fish parts and ask students to pose questions about what the parts do for the fish. As it is described, the lesson does not necessarily engage the students’ thinking.

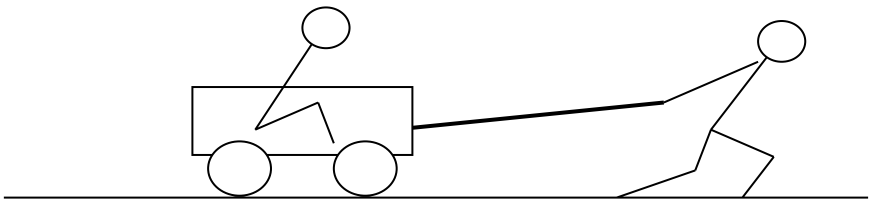
Response “A” and “B” align only with knowledge-level objectives, whereby the intent is for students to know the vocabulary. Knowing formal names of body parts is not a necessary criterion for associating form and function and the approach is not inquiry.

Response “D” suggests that a good inquiry lesson is never teacher-centered. A teacher-centered portion of a lesson can be inquiry-oriented by engaging students through modeling of investigative activities. Teachers can provide students with questions, data, and explanations; all the while discussing the reasoning processes that lead to justification for claims.

Response "E" is not the best because it suggests a good lesson must always be "hands-on." Hands-on does not ensure inquiry nor does it ensure students will connect the lesson to the real world. The teacher could engage students through questioning and other scenarios familiar to students, without needing to have students observe real fish – though this would be ideal.

EXAMPLE 2: Teaching approaches for force and motion

A useful activity for teaching force and motion is to have one student sit in a trolley with little friction while another can pull it along by exerting force on the handle.



The goal is that students gain a conceptual understanding of the relationship between motion and force, viz. that an applied force will cause an object to change its motion, i.e. speed up or slow down. (Newton's second law).

Five teachers have five different lesson plans for using this activity to teach the relationship between force and motion. Which plan below would be best?

A. Mr Adams starts by writing a heading on the board: 'Newton's Second Law of Motion', and dictates the law (in conceptual terms) for students to write down. He then explains the law and illustrates it with a diagram of a trolley being pulled. At any stage he gives students the opportunity to ask questions. Finally he has students verify the law experimentally by checking what happens to a trolley when a person pulls it with a constant force.

B. Ms Burke first has students explore what happens to the trolley when a steady force is applied to it, and asks them to describe the kind of motion that results. She elicits the focus question of how force and motion might be related, then asks for suggestions for a 'law' that would describe their observations. Having put forward a proposed law (or laws), students then test it by making predictions in various situations and trying out. They finally write their own statements of the law they have generated.

C. Mr Campos gives students freedom to try out anything they wish with the trolleys, intending that they should be drawn in to the hands-on activity and discover on their own the relation between force and motion. He does not impose structure nor tell students what to do, but is available for discussion, in which he does not give 'answers' to questions but instead asks questions in return. At the end of the session he does not provide the 'correct' law, since the point is for students to discover their own.

D. Ms Davis, as a prelude to Newton's second law of motion, defines the term acceleration and has students write it down. She then explains the concept carefully with examples. Thereafter she presents Newton's second law in the form 'acceleration is proportional to net force'. Students then verify the law by doing the hands-on trolley activity.

E. Mr Estrada feels that the textbook treats force and motion clearly and correctly. Thus he has several students in succession read paragraphs aloud from the book, and encourages students to ask if they don't understand something. He then demonstrates the law for the whole class with the trolley activity and two students assisting, to verify the textbook statement.

Note that this item may be most suited to formative use because of the length of its options.

Comments on Example Item 2

Only options B and C represent inquiry approaches, but C is essentially unguided discovery. B addresses all of our inquiry pedagogy criteria, while the unstructured nature of option C makes it hard to know which criteria might be attained in a class. The other options A, D and E present the conclusions of science first, then explain and confirm them, the antithesis of inquiry and investigation.

This approach is completely non-inquiry, though organised and methodical. The lesson is a rhetoric of 'conclusions first', to paraphrase Schwab. Experiments are seen as confirmatory not investigative.

A good inquiry approach, generating questions, ideas and concepts from exploration. Students propose a possible law from evidence and test it. Guided inquiry and investigation, appropriately structured, as advocated by standards.

Unstructured and unguided discovery for the most part. It is unlikely that students will be able to make sense of the activities or reach the desired learning outcomes. Pure discovery is not advocated, and Klahr's research shows it to be ineffective.

Presents conclusions first, again the antithesis of inquiry. Moreover, difficult concepts (acceleration) are introduced and formally defined in a way that is unnecessary at this level and will likely interfere at this stage with developing the desired conceptual understanding.

This is a dreary passive class activity, though the teacher may be seeking to avoid 'teacher talking' to some extent. Approach is non-inquiry, little engaged. Experiments seen as confirming book knowledge rather than generating knowledge.

EXAMPLE 3. Anomalous results in a classroom investigation on earthworms

Earthworm investigation

Ms Lefevre's third grade class has been doing a long investigation activity with earthworms. Besides teaching her students about the basic needs of earthworms, Ms Lefevre also wants to develop their skills of observing, investigating, recording and seeking patterns.

Several groups had been making observations and taking data over some time, and she brought the class together around the data chart, so that they could all look for patterns in their observations. She wanted her students to rely on evidence to develop knowledge. During this analysis, a student pointed out that data collected by one group seemed to contradict that of another group.

What should Ms. Lefevre do in this situation?

A. Tell the students which of the two sets of data is correct and cross out the other data, so that none of the students get wrong ideas about earthworms.
B. Ask the students to suggest ways to resolve the issue, valuing any response that relied on evidence, e.g. re-examining recorded data or comparing procedures, repeating or taking more observations.
C. Ask everyone to look at the two data sets and to pick the one they thought was right. Then have a show-of-hands vote to see which one should stay and which should be crossed off. This would ensure that the data that remained reflected the majority view.
D. Tell the students that since there was conflicting data and it wasn't clear which was right, she would it up and get back to them the next time. Then move on to look at other aspects of the observations.
E. Ask the students to read through the topic resources again to see if they can find information that will resolve the dispute.

<u>*Comments on Example Item 3*</u>

The desired response is B. This response most closely mirrors what scientists do when variations occur in data. They first recheck and rethink their observations, looking for sources of error. Then they often make new observations under more closely prescribed conditions. In this way, they hope to gather enough data to see clear patterns.

Items A, D, and E essentially sideline the classroom inquiry to refer to an outside source, a poor choice when evidence or procedure is available to resolve the dispute.

Item C involves voting, which discounts certain data based on reasons other than the data itself. In science inquiry, all data is important initially, and data can only be discounted when error in procedure, observation or recording can be identified. Otherwise the data counts, even if it seems not to fit or illustrate a clear pattern.

2. Open-ended assessment instruments

2.1. Inquiry survey for teachers

Rationale: this set of questions provides insight to (or can be used as a (self-) reflective tool about) teachers' conceptions about science inquiry (Van Hook et al, 2009). It may reveal barriers (such as classroom management) to inquiry-based science teaching that teachers must face, and determine pre/post changes in teachers' ideas and attitudes during a development process (ibid).

When to use: it can be used as a formative or a summative assessment as well; it can be used as pre/post survey accompanying a collaborative (participatory) development process involving scientists and/or educational researchers and teachers

How to use: this open-ended assessment tool can be used in individual or focus group interviews, or as a paper-pencil tool, but even in a digital environment. For the graduate pre-service teachers, questions 7-12 asked about "a future college classroom" instead of "the upcoming academic year in your classroom".

What type of data it can collect: this tool can either provide a state-of-the-art reflection on conceptions linked to inquiry-based science teaching or it can support evidence on whether and how teachers' conceptions change during a (collaborative) development process. It determines the state of the responder' ideas, attitudes and concerns about inquiry-based science teaching (Van Hook et al, 2009).

Questionnaire:

1. How would you define learning through inquiry?
2. Describe a lesson where inquiry-teaching methods are being used.
3. What skills do students need to have in order to do inquiry?
4. What skills do teachers need to have in order to teach using inquiry?
5. Describe a classroom environment conducive to inquiry
6. How often did you use inquiry in your classroom this past year? (Example: Once a week, twice a week, once a month, once a quarter)
7. What do you see as the advantage of teaching for inquiry during the upcoming academic year in your classroom?
8. What do you see as the disadvantages of teaching for inquiry during the upcoming academic year in your classroom?
9. Are there any people or groups who would approve or disapprove of your teaching for inquiry during the upcoming academic year in your classroom?
10. What things would encourage you or make it easier for you to teach for inquiry during the upcoming academic year in your classroom?
11. What things would discourage you or make it harder for you to teach for inquiry during the upcoming academic year in your classroom?
12. Do you have any other thoughts or concerns about teaching for inquiry during the upcoming academic year in your classroom?

2.2. Views about Scientific Inquiry (VASI) questionnaire

Rationale: It is an open-ended instrument created to measure students' (6th grade or older), teachers' and scientists' understanding about the nature of scientific inquiry (Lederman et al, 2014). As for teacher training, it intends to make inquiries about teachers' knowledge about how to transfer their own knowledge on nature of science and scientific inquiry into classroom practice and having pre- or in-service teachers explicitly reflect on the structure of the subject matter they are learning for teaching.

When to use: it can be used as a formative or a summative assessment as well.

How to use: it is preferred to be administered without set time limit for completion and under controlled conditions. Usually it takes some 30-45 minutes for responders to complete the questionnaire. Preferably as detailed and illustrated information should be gathered from responders as possible.

What type of data it can collect: it refers to the level of understanding (using categories such as informed, mixed, naïve and unclear) of inquiry processes; developers suggest for accompanying the questionnaire with interviews before evaluation in order to validate data.

The questionnaire:

1. A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed birds that eat similar types of food, tended to have similar shaped beaks. For example, birds that eat hard shelled nuts have short, strong beaks, and birds that eat insects have long, slim beaks. He wondered if the shape of a bird's beak was related to the type of food the bird eats and he began to collect data to answer that question. He concluded that there is a relationship between beak shape and the type of food birds eat.
    a. Do you consider this person's investigation to be scientific? Please explain why or why not.
    b. Do you consider this person's investigation to be an experiment? Please explain why or why not.
    c. Do you think that scientific investigations can follow more than one method?
        - If no, please explain why there is only one way to conduct a scientific investigation.
        - If yes, please describe two investigations that follow different methods, and explain how the methods differ and how they can still be considered scientific.
2. Two students are asked if scientific investigations must always begin with a scientific question. One of the students says "yes" while the other says "no". Whom do you agree with and why? Give an example.

3. a. If several scientists ask the ***same question*** and follow the ***same procedures*** to collect data, will they necessarily come to the same conclusions? Explain why or why not.
   b. If several scientists ask the ***same question*** and follow ***different procedures*** to collect data, will they necessarily come to the same conclusions? Explain why or why not.

4. Please explain if "data" and "evidence" are different from one another. Give an example.
5. Two teams of scientists are walking to their lab one day and they saw a car pulled over with a flat tire. They all asked, "Are different brands of tires more likely to get a flat?"
   - Team A went back to the lab and tested various tires' performance on three types of road surfaces.
   - Team B went back to the lab and tested one tire brand on three types of road surfaces.

Explain why one team's procedure is better than the other one.

6. The data table below shows the relationship between plant growth in a week and the number of minutes of light received each day.

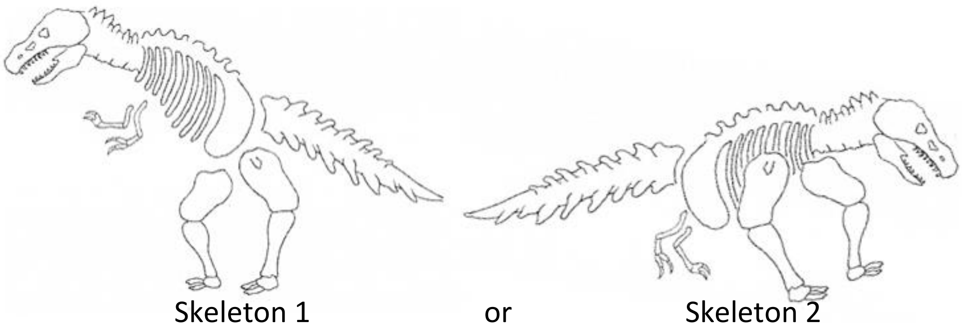
Minutes of light each day	**Plant growth-height (cm per week)**
0	25
5	20
10	15
15	5
20	10
25	0

a. Given these data, explain which of the following conclusions you agree with.
*Plants grow taller with **more** sunlight.*
*Plants grow taller with **less** sunlight.*
Or

*The growth of plants is **unrelated** to sunlight*.

b. Why did you select this conclusion?
c. Are the data what you expected? Why or why not?

7. The fossilised bones of a dinosaur have been found by a group of scientists. The scientists put the bones together into two different possible arrangements.



a. Describe at least two reasons why you think most of the scientists agree that the animal in *skeleton 1* had the best positioning of the bones?
b. Thinking about your answer to the question above, what types of information do scientists use to explain their conclusions?
c. When scientists do any investigation, what type of information do they use to explain their conclusions?

2.3. Knowledge Structure of Nature of Science and Scientific Inquiry (KS4NS) questionnaire

Rationale: It is an open-ended instrument created to investigate about teachers' understanding about the links between the nature of science and scientific inquiry in the context of science teaching (Bartos, Lederman, 2014).

When to use: it can be used as a formative or a summative assessment as well as a tool supporting any professional development activities.

How to use: it is preferred to be administered without set time limit for completion and under controlled conditions. Preferably as detailed and illustrated information should be gathered from responders as possible. It is preferred to obtain demographic data on responders too (including educational background, teaching experience, philosophies of (science) teaching and current teaching environment and settings), and it is highly recommended to use interviews for refining data collected via the survey. It is best used as a paper-pencil tool.

What type of data it can collect: it refers to individual knowledge structure of teachers, which may help to better understand or contextualise the teaching practice as well as the teacher's stage and needs in their individual professional learning journey.

The questions:

1. What concepts and/or ideas comprise nature of science and scientific inquiry? Please include any and all concepts and/or ideas that you feel comprise nature of science and scientific inquiry.
2. If you were to make a diagram of nature of science and scientific inquiry, either separate or together, what would it look like?
3. Have you ever thought about nature of science and scientific inquiry in this manner before? Please explain.

2.4. Spider web, self-assessment tool

Rationale: this tool is suitable for quick and also continuous (systematic) self-assessment of practitioners, via assessing experience gained by using a specific approach, tool or instrument.

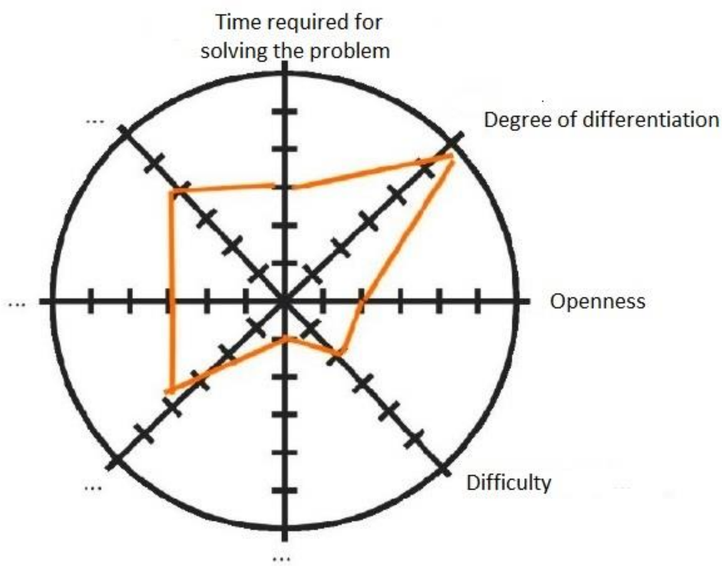
When to use: it is best to introduce during a teacher training, and then teachers can use it independently.

How to use: this tool is the simplest to use on paper, but a digitalised version can also be used (clicking on points and saving the completed graph); the spider web tool is a precious element of a learning portfolio.

What type of data it can collect: when used for evaluating the results of piloting with a specific activity, researchers can collect data about what practising teachers think about the suitability of the activity or task; for teachers it offers a helpful tool for upgrading to reflective professionals by rigorous reflection on their own teaching; moreover, when teachers are free to opt for analytical aspects during a teacher training session, trainers (and researchers) can obtain information about what points are the most relevant for practitioners about a specific inquiry activity (or inquiry based teaching in general).

For this tool, users choose eight priorities they want to achieve by introducing the specific task. In other cases, they opt for pedagogical aims or aspects of inquiry learning that they address with a specific task type.

This tool was successfully introduced in the German SINUS modules. Here is an example from SINUS:



Picture 1: Spider-web tool (Stäudel, 2003)

The advantage of this tool is that it can be easily digitalised and if used in relation with one specific task or activity, collected data can be easily visualised and it is informative for the task developer or anyone who is willing to adapt the task[1].

The disadvantage of this tool is that it is a relative measure (even if the eight aspects are given), reflecting the culture and language of the user, therefore is difficult to use for comparative assessment. However, the tool can still be used for raising awareness of teachers to aspects of inquiry approach (teaching-learning) or scientific thinking. Also, it can be a research question, what aspects of tasks teachers consider relevant (in case of non-prescriptive spider-web tools).

[1] In Hungary, in an experiment involving 44 teachers (lead by the Hungarian Institute for Educational Research and Development) this tool was used with eight aspects of scientific inquiry as well. These eight aspects were: (1) observation with proper senses; (2) clustering and categorisation; (3) recognising patterns; (4) causal reasoning; (5) using evidence; (6) reflecting on problems; (7) collaboration; (8) communication. Teachers were asked to evaluate their activities along these eight criteria using the tool. Different activities lead by the same teacher were compared and reflected on during the continuous professional development course. This way, strengths and weaknesses of specific practices could be analysed and then developed.

2.5. Tool for assessing aspects of scientific thinking

Rationale: the purpose of this tool is to support reflection on the given teaching practice (or a specific learning cycle or activity) by the teacher; by collecting examples or evidences supporting a notion about how aspects of scientific thinking are developed by their practice, teachers can see their strengths, and also find points to further develop (for instance aspects that they tend to neglect) – although in some cases students' age characteristics would not allow the development of all these aspects, therefore neglected aspects should be thoroughly and carefully reflected on in the light of the targeted student group.

When to use: it is best to use during and after a professional learning course.

How to use: it can be used either on paper or in an electronic version (any platform allowing questionnaires can be suitable for creating a digital version too).

What type of data it can collect: this tool can point to characteristics of a specific learning cycle or activity, or (if used consequently and continuously) a teachers' practice; this way it is relevant for further developing learning cycles or supporting individual learning of teachers.

This tool is adapted from PISCES, part of S-TEAM FP7 project (Smith et al 2010) and can be relevant for open-ended assessment of tasks:

Aspects of scientific thinking	**Analysis**	
	Supported/ Partly supported/ Not supported	**Evidence (example)**
I observe with any or all of my senses as required.		
I categorise what I observe as things and events.		
I recognise patterns in the categories of things and events.		
I form and test hypotheses.		
I think about cause and effect.		
I effectively support theory with evidence.		
I visualise.		
I am aware of my thinking and control it.		
I use metaphor and analogy		
I use the 'confirm early-disconfirm late' heuristic		
I collaborate in thinking		

2.6. V-diagram

Rationale: this tool is useful for analysing problem situations and finding possible solutions, as well as better understanding classroom inquiry learning processes in their complexity; it proved to be useful in mentoring teacher trainees and teachers.

When to use: it is best to use during the teacher training or for mentoring teachers.

How to use: this tool is best used on paper or flipchart or (in an electronic version) on smartboard.

What type of data it can collect: this tool is not meant for data collection but for better understanding complex processes and problem situations[2].

A V diagram is a graphical organiser that can be used as a tool for problem solving (Novak, Gowin, 1983). It was originally developed by Bob Gowin as an aid for students to understand the structure of knowledge and how human beings are able to construct new knowledge (Novak & Gowin, 1984, p. 55). In the literature also known as Gowin's knowledge-V or Vee-heuristics, this tool is meant to visualise the activities and different steps integral to all types of research are made visible, also the type of research that constitutes an open investigation. V diagrams were originally developed in order for students and teachers to develop a better understanding of what takes place during investigations in the science classroom.

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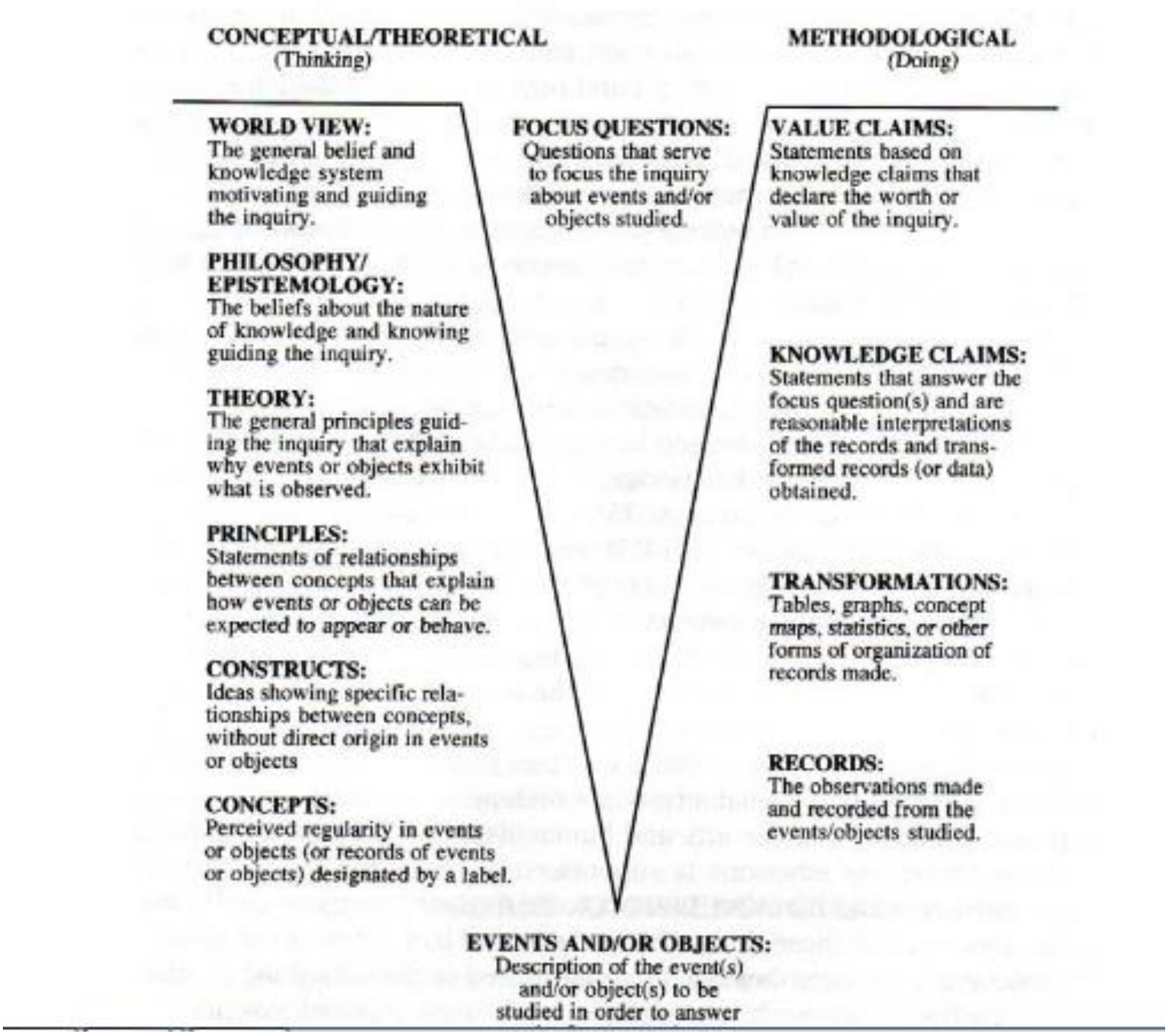
[2] In S-TEAM project some partners experimented with using this reflective tool in order to structure teachers' thinking (S-TEAM, 2010). It seems that in some countries, where teacher training focuses more on pedagogical (content) knowledge and reflection, this tool might work well; but in other countries, where science teacher training focuses on science content knowledge and related didactics rather, teachers will not be likely to use this tool with enthusiasm. There are also video learning materials available on using the V diagram in chemistry lab learning (e.g.: http://stream.vasa.abo.fi/flash/tritonia/kurten.php?file=kurten/0.flv)



Picture 2: Gowin's knowledge V (Novak, Mintzes & Wandersee, 1999, p. 10. quoted by Forsman, Kurtén-Finnäs, 2010, p.20)

2.7. Target document and commentary document

Rationale: these documents[3] help planning and assessing activities or learning cycles; the target document helps to establish a hierarchy of targets, aims and objectives, while the commentary document is meant to reflect on the activity of teaching

When to use: it is best to use during a professional learning course and then by teachers in their daily practice

How to use: the most convenient form to use is the electronic version or on paper

What type of data it can collect: it can show individual learning pathways of teachers and also are suitable for tracing and tracking the travelling of a module or a task: how and why it was used by different teachers in different context (student groups, learning environments). The two tools help teachers prioritize their aims, better understand target hierarchy and more consciously choose task types and design activities. (Réti, 2015) Also, they help them reflect on original aims and better plan an adaptation of a learning module or a task. When analysing these documents, researchers can reflect both on individual learning journeys of teachers, general features of some modules or task (who chose them and why, what reflections, suggestions or remarks users had). These documents proved to be good tools to understand how the modules can "travel" from one school or teacher to another.

[3] These two tools originate from the SINUS programme (SINUS tools: http://www.sinus-transfer.de/), which was developed in Germany, and partly due to the Rocard report and several FP7 projects, adapted in many other European countries. In SINUS, originally they served to prepare and support teachers' reflection connected to modules of the professional learning course. There are several adapted versions of the two documents.

Target document

School:	
Teacher:	
Class:	
Subject:	
Date:	
TARGET:	☐ pilot ☐ trial ☐ adaptation

I see the following opportunities in my class/ group / with my students in science education:

I decided to work with the task…

Title:

Emphases:

I would like to reach the following with my work …

Goals:

Objectives:

I would like to use it in he following ways:

☐ Individual support (talent care/…):

☐ Group-work, community building:

☐ Differentiation:

☐ …………………………………………..

How are the steps of inquiry cycle represented in the activity?

□ Orientation:

□ Conceptualisation:

□ Investigation:

□ Conclusion:

□ Discussion:

My teaching aims related to inquiry learning:

□ Problem-based thinking:

□ Experimenting, hands-ons:

□ Students’ autonomy:

□ Communication (presentation, argumentation, etc.):

Commentary document

Task title:	
Task type:	
School:	
Teacher:	
Class:	
Subject:	
Date:	

Before using the task…

□ I made no changes □ I made minor changes

□ I made an adapted version □ I transformed the task

□ ………………………………………………….

When introducing the task at my lesson, I experienced… (positive & negative)

□ students: □ myself: □ ……………………………:

I suggest the following changes…

□ in the content:

□ in the processes:

□ in the assessment:

□ ………………………………………………..

2.8. Set of open assessment questions

Rationale: the purpose of this set of questions is to help reflection on teaching-learning activities, hence developing the pedagogical knowledge of teacher trainees or teachers.

When to use: it can be used linked to any activity, either during or after a training course.

How to use: either electronically (digitally) or on paper; reflection is also possible orally.

What type of data it can collect: this tool is not meant for data collection but for generating conclusions or supporting argumentation linked to inquiry activities (e.g., own experience after group-work or piloting in classroom with inquiry materials).

These questions may be suitable for generating conclusions or comments on tasks as well as in mentored dialogues scaffolding pedagogical knowledge of teachers. The questions were adapted from the set of inquiry workshop for teachers by Exploratorium (2006). Some questions were added from the experiences of Spice project (about adapting science tasks or lesson plans at a European level, Gras-Velázques, 2011), especially on time and infrastructure, which seemed then to be the two most restrictive factors in adaptation of good practices.

Level of learner control

- How much control does the learner have over what happens?
- Can the learners ask the questions?

Science content

- How does the task contribute toward learning content?
- How does the focus of the task relate to science curriculum?

Science attitudes

(e.g., respect for evidence, curiosity, perseverance, creativity and inventiveness, cooperation with others)

- In what way does the task foster curiosity and other scientific attitudes?

Science process skills

(e.g., observing, interpreting, planning, questioning, communicating)

- What skills are practiced in this task?
- What skills are required in this task?
- What aspects of science competence are enhanced by working with this task?

Time and task management

- How much time did it require to prepare the task?
- How much time did it require to do and assess the task?
- Did you need to acquire any special equipment (that is not used regularly in your classes)?

3. Interview protocols

3.1. Convergent interview

Rationale: this is a qualitative research method, which from a relatively low number of interviews can draw meaningful conclusions and provide an overall picture of a complex situation; in this context, it is suitable for evaluating a pilot phase or a training course (and can also be used as a type or instrument of action research related to mentoring teachers).

When to use: preferably after a training course or while mentoring teachers.

How to use: according to the protocol, this method needs a set of interviews and at least one or two researchers.

What type of data it can collect: using this method one can highlight causes of specific problems or details of a complex process or situation, while getting a general understanding of it.

This type of interview can be used in two main ways.

(1) *Efficient way of data collection*. First of all, it is suitable for reasonably rapid data collection: in a limited number of interviews, it may already provide a general overview of strengths, problem areas and the utilisation of the inquiry approach (teaching). Secondly, this can establish the further foci of research, or can be revealing a diversity of points of views.

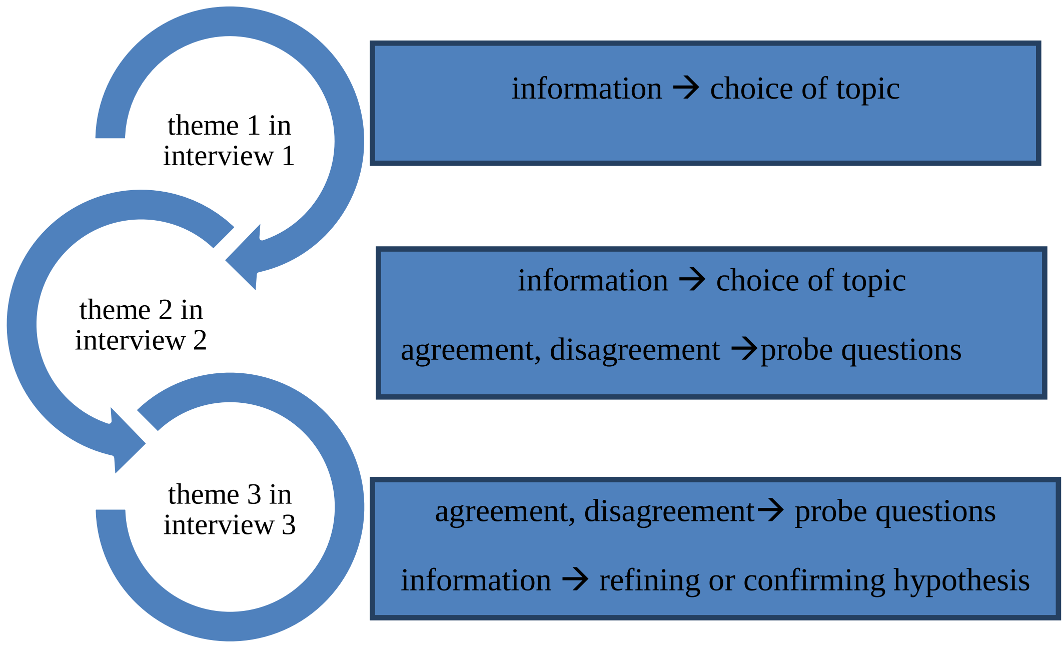
(2) *An iterative process similar to or supporting action research*. Although convergent interviewing does not seem at first to be really participative, but due to its cyclic nature and its use of dialectic, it may constitute an action research cycle too, which might be very useful in the development and piloting phases of the project. As convergent interviews are built up by subsequent pairs of interviews, each of which consisting of a data collection (observation) and a reviewing (reflection) phase (as this method uses the data emerging from the previous interviews to plan later ones), the interview series form a larger cycle.

Convergent interviewing (Dick, 1990) is flexible, efficient yet rigorous qualitative method, which has five main features:

1. It is a set of interviews, in which each individual interview begins with an open-ended statement. This statement defines the broad topic of the interview. The interviewer, without asking detailed questions, then encourages the participant to talk freely about the topic. Therefore, in the early phase, the information is offered by interviewees and not elicited by pre-formulated research questions.
2. Later in each interview (except perhaps the first one or two) probe questions are asked. The probes are developed from earlier interviews. They are driven by the data from those earlier interviews. They have two purposes: to challenge apparent agreements between earlier participants; and to explain disagreements. In answering the

probe questions, the participants in effect interpret the earlier agreements and disagreements.

3. In convergent interviews, generally, very diverse samples are used rather than random samples. As far as possible, all interest groups are represented. The purpose is to increase the diversity of responses. In general, first a person is chosen who will potentially reveal a good amount and quality and information. Then sample grows with an intention to refine and clarify previous information, adding ever newer aspects or points of views too.
4. The interview process can be refined as the set of interviews proceed. The purpose is to improve the process by making use of and also supporting the researcher's growing understanding.
5. The interviews are embedded in a process to involve people from the effected community so that people who have to act on the results of the interviews understand and own some of the results.



Picture 3: Spiral model of convergent interviews (Dick, 1990)

Convergent interviews are built up of the following steps.

1. Basic environmental scan

In order to choose the proper subject for the first interview, it is necessary to get to know with the context: who is acting and how, who can influence the results and how. In our case, it is some inquiries about teachers using the platform: probably if convergent interviews are used in local/ national context, this environmental scan is a reasonably easy task.

2. Introduction

First of all, this phase is about creating a relaxed atmosphere and giving basic information (brief details of the interviewer, the purposes, data processing and the access to any information revealed in the interview). I would choose here to report information in such a way that I preserve the anonymity of participants, and I would also prefer to make the same information available to everyone involved in one community.

"I'll report the results of the interviews only in summary. I'll do it in such a way that you can't be identified as the source of any information. Any information that I give to anyone is also available to you."

"I've been asked to do this interviewing by Ark of Inquiry project. Data collected here will be available for a team of researchers involved in the project. A final report on findings will be issued and available at Ark of Inquiry website."

3. Asking an opening question

A broad question will define the general area of inquiries without being more specific. This should be a question or a statement that refers to the topic but which is almost free of content.

"I'm interested in learning how working with Ark of Inquiry platform works. I'd like to know what's good about it, and what can be improved. So, what do you like, and what do you dislike, about working with this platform?"

"Tell me about your experiences with Ark of Inquiry platform."

4. Active listening: keeping the interviewee talking

The crux of this method is to let and keep the interviewee talk, without asking specific questions. One interview can last for about 30-60 minutes. Techniques of metacommunication (e.g. nodding, positioning the head and hands, etc.) as well as active listening and 'minimal encouragers' can be applicable here. The interviewer should be (or at least look) genuinely curious about the interviewee's experience. Paying attention and efforts made to understand what it is like to be this person in this situation. One can also improve the depth of rapport and the quality of information by the use of careful self-disclosure. This has the effect of making it a little more like a conversation, but the interviewer must be rigorous about not shaping the interviewee's responses.

It is useful in this stage to take key word notes (preferably without losing eye contact); or otherwise one can memorize the themes as they arise. Recording the interview is another option, or having two interviewers is a third one (one talking to the interviewee, the other taking notes (in this case, from the very first moment, both interviewers should be involved, and they can eventually change roles in the set if interviews). In case of recording, one should give the chance to the interviewee to turn the recording off if they wish.

"This is the pause button. Please use it any time you wish something not to be recorded. Please use it any time you want me to erase something you've just said."

5. Probe questions

Towards the end, the interviewer asks the probe questions developed from earlier interviews (or from the current interview). There may not be any probe questions in the first pair of interviews.

The probe questions contribute much to the efficiency of the technique. When the researcher finds an agreement during the interviews, it should be tested by probe questions seeking exceptions. When the researcher finds a disagreement (or conflicting views), that should be tested by seeking explanations. Probe questions serve clarification, therefore some of them refer to revealing more details about a situation, a problem or the context (background) of a point of view.

When developing probe questions, the researcher is looking for themes mentioned by two or more participants (or by one participant and an earlier participant) via comparing adjacent interviews. Suppose the two participants agree. For instance, both may say *"The tasks I found on the Ark of Inquiry site are not well prepared."* When this happens, devise a probe question or questions to find exceptions. *"What's good about the preparation of tasks that you do?"* Or *"Who from your colleagues is best at preparing tasks?"* Or *"When do you feel that you prepared a task well?"* Or *"Could you describe a task that is really well prepared?"*

Sometimes interviewees will disagree. One may say *"Tasks on the site are poorly organised"*. The other may say *"One of the best thing is how tasks are organised on this site"*. Both have mentioned the theme of organising tasks, but they have different perceptions of it. Now the task is to develop a probe to explain the disagreement.
"Some have said that tasks on this site are organised well; some have disagreed. What do you think? Help me to understand why there are differences of opinion about this."

In this way, the researcher "challenges" the interpretations arising from early (or actual) interviews, and that leads to deeper understanding the context. Probe questions make this type of interview "convergent", as these questions will lead to a clearer view (or shared understanding) of the original topic. Also, probe questions protect the researcher from his/her own biases. If the questions are determined by comments in previous interviews the researcher gets protected to some extent from imposing his/her own preconceptions on the data (which is crucially important with qualitative research).

By seeking exceptions the researcher allows disconfirmation of data and interpretations. The disagreements and the explanations that probe questions reveal will navigate towards a potentially available set of further data.

It is also useful in this phase to ask who else the interviewer ought to talk to, *"... especially people whose views are different to yours".* This serves to check the sampling.

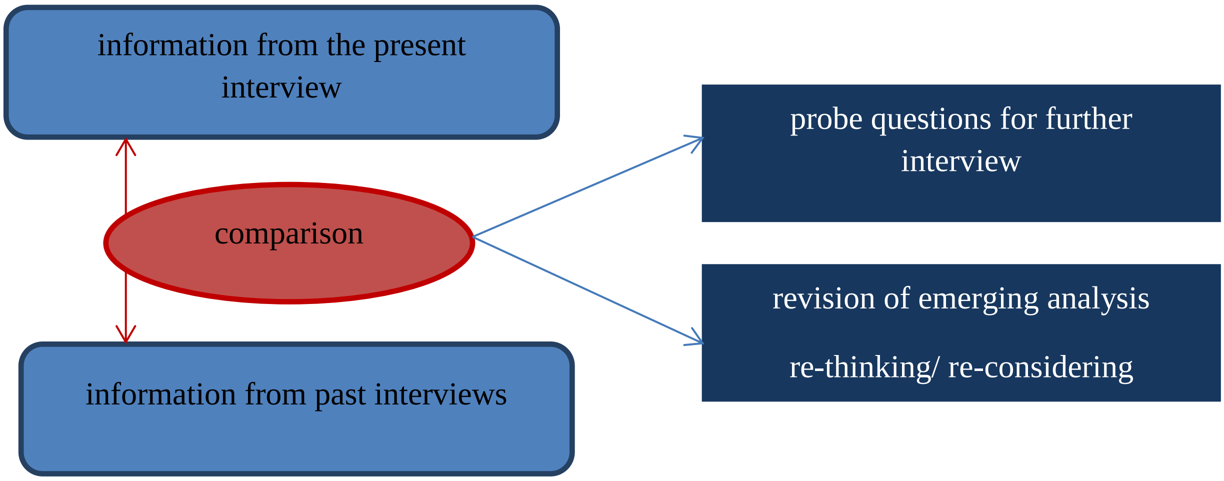
6. Inviting a summary

At the end of each interview, the interviewer calls for a summary of the key points having been mentioned. This should be later compared to the researcher's own mental summary or notes. Finally, the interviewer should thank the interviewee genuinely, very briefly repeating the key points about what will happen to the information, and how the person can access it.

7. Reflection

While still fresh in mind, the researcher prepares notes and reflects on possible further interviews and probe questions.

After each interview, the researcher should also review the applied methods. Is the opening question working as intended? How appropriate does the overall interview format appear to be? Does the sample appear to include all of the various points of view?



Picture 4: Summary of convergent interviewing (Dick, 1990)

Guideline for convergent interviews

(1) introduction

(a) in case of first interview:

- the interviewer is introducing himself/herself
- aim of the interview, the course of the interview
- data processing and accessibility, for example: *„Only the summary of data gained here will be available for public. We will introduce conclusions and exemplars in a way that the information resource (for example the name of the teacher or the educational institute) will not be identifiable. Any information published from this research will be accessible for you. "*

(b) later (if interviewing the same person for the second or third time):

- warming up, brief reflection on previous interview

(2) giving an open statement or a question, **imposing the theme** – for example: *„Tell me about why you decided to work with inquiry based teaching"*, or: *„I'd like to know how teachers could feel safer when experimenting with inquiry based teaching. Could you tell me about how you felt when you first piloted with (or adapted) an inquiry activity? "*

(3) active listening: interviewee talks about 30-60 minutes. The interviewer takes notes or records the interview.

(4) probe questions: mainly focusing on parts on which the interviewee (in the „free" session) has not reflected.

(5) finishing

- It is worth asking the interviewee if he or she would like to mention something else. Also, if he or she recommends another interviewee, the opinion of whom can be relevant for the research.
- Inviting the subject for a summary: meanwhile, mentally comparing his or her perception with ours.
- Thanking the interview and repeating information about data and accessibility.

5.2. Unstructured interviews with (in-service or pre-service) teachers

Rationale: this qualitative research method is suitable for revealing new areas for research and highlighting the underlying reasons for some phenomena already described by quantitative or other research.

When to use: it is best to use either before or prior to and after a professional learning course.

How to use: this method involves free discussion with (pre- or in-service) teachers.

What type of data it can collect: unstructured interviews may add further information to the learning processes linked to inquiry based teaching.

The participants of the unstructured interviews come from groups of teachers piloting or working with inquiry based science teaching and learning materials.

For the interview we suggest using no special infrastructure for two main reasons: (1) some of these (like mirror rooms) are not available in most educational institutions (specially schools); (2) observing informal characteristics of original settings (like a classroom) during the interview sessions may add to the verbal information gained through the interview.

A proposed guideline of the interview is as follows:

2 min	***Greeting***	• greetings, introduction • purpose and time span of the interview, data processing and accessibility
5 min	***Introduction***	• introducing the research and the context within Ark of Inquiry project • brief and mutual introduction of interviewee and interviewer
25 min	***Experience***	• talking about experiences with inquiry based teaching
5 min	***Strengths***	• if not mentioned in the previous section
5 min	***Problems, weaknesses***	• if not mentioned in the previous section
3 min	***Closing***	• thanking for the opportunity • repeating information about data processing and accessibility

5.3. Features of inquiry learning: structured interview questions

Rationale: the purpose of this structured interview is *"to elicit practitioners' views of the 'essential features' of science inquiry learning including strategies and approaches"* (Levy, Lameras, McKinney & Ford, 2011) including beliefs, intentions and self-reported actions for inquiry learning in science.

When to use: it is best to use in the beginning of a process.

How to use: 20-30 minute face-to-face (or video-conference) interviews.

What type of data it can collect: views on how expert practitioners/researchers conceptualise and/or carry out inquiry learning in science education, including particular approaches and strategies.

Interview Questions

Question	Responses	Keywords
1. Could you please explain what you understand by the term inquiry learning? What are its main features and how is it different from other forms of learning?		
2. Could you please describe how you would develop/design an inquiry investigation/activity? (Follow-up: could you give an example of an inquiry activity?) (Prompts: elements of design: learning outcomes, inquiry questions, inquiry activities, teaching strategies, assessment, support roles, students' skills, resources, technology, environment, etc.)		
3. Could you please explain why you adopt inquiry learning (or why you believe it is important)? Prompts: benefits? at different levels of education?		
4. Could you please describe the factors that identify successful achievement in inquiry learning and teaching? (prompt: learning outcomes, teaching strategies, assessment, students' characteristics, content, tools, resources activities, nature of lesson, technology...)		
5. How do you generate ideas for creating inquiry-led science investigations (Prompts: prior experience, discussion with colleagues, research-based evidence, case studies, conference presentations, from students)		

Question	Responses	Keywords
6. Do you use (or recommend) any particular models for designing inquiry activities (e.g. a learning cycle)? Please explain these if you do. Also, do you use or recommend any particular tool or technology to design inquiry activities? (e.g. concept map, web-based tool)		
7. What do you consider to be the most problematic when trying to use inquiry learning? (Prompt: finding an appropriate inquiry-based strategy; linking tasks to learning outcomes; time-consuming; no institutional support; development of appropriate assessment). Follow-up: How do you deal with these?		
8. How and when do you evaluate the inquiry-based investigation /activity (Follow up: what criteria are used to deem it acceptable?).		
9. What methods do you find useful for your own professional development regarding inquiry teaching? (Prompt: any particularly effective training; community of practice approach; science teacher as curriculum designer; blended learning etc.)		
10. Finally, are there any other considerations that we haven‘t covered so far that you feel are important for inquiry learning in science education?		

Appendix 8.12 Web-based materials for Scientists

Right below we provide the content of the web-based materials for Scientists as they appear on the Ark of Inquiry website [see www.arkofinquiry.eu/research].

Dear scientist,

In the context of Ark of Inquiry project, you are expected to contribute in supporting the network for teachers in understanding and using the Ark of Inquiry material on RRI, so that they can effectively work together with the pupils. You will also have the opportunity to evaluate inquiry activities and to suggest new ones.

To enhance your role and contribution towards this direction, we developed several web-based materials that will help you familiarize yourself with:

- the definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry,
- the phases of inquiry that learners go through during their engagement of inquiry activities,
- the skills and practices that are involved during inquiry learning.

Appendix 8.13 Web-based materials for Scientists: Definitions of two major concepts used in the context of our project, namely Responsible Research and Innovation (RRI) and Inquiry

What is Responsible Research and Innovation (RRI)?

Responsible Research and Innovation (RRI) has been defined as an inclusive approach that allows several societal actors (e.g., researchers, citizens, policy makers, business, third sector organisations etc.) to interact during engaging with research and innovation process with the express purpose to align both the process and its outcomes with the values, needs and expectations of European society (Science with and for Society, 2014). More specifically, citizens in democratic societies are expected to engage in decisions regarding new technologies when cultural, environmental, social, economic or ethical values are at stake. Preparing citizens to engage constructively in discussions about whether a new technology is beneficial or harmful to society requires providing them with a basic understanding of how to evaluate scientific research and innovation. Thoughtful and informed thinking comes from making judgments about the credibility of different types of evidence. Citizens need to be skilled in asking critical questions, evaluating qualitative and quantitative data, and discussing RRI issues with a variety of societal actors. Discussing science policy issues with a variety of stakeholders ensures that citizens are exposed to information from different perspectives. Likewise, interacting with a diversity of stakeholders increases the likelihood that persons in positions of authority feel a sense of responsibility to carefully consider socio-scientific issues. A greater involvement of informed citizens in the research and innovation process fosters inclusive and sustainable outcomes that ensure public trust in the scientific and technological enterprise. Although RRI is related to and relevant for all scientific domains, it has been argued that especially in the STEM domains in which emerging technologies encounter ethical questions and choices, RRI awareness is important (e.g. Sutcliffe, 2011).

The Ark of Inquiry project aims to foster RRI by teaching pupils core inquiry skills needed to evaluate the credibility and consequences of scientific research and by offering opportunities for pupils to engage with different societal actors involved in the research and innovation process. It is important that pupils experience inquiry activities outside of the formal educational setting and become aware of the broader community of people involved in research and innovation. Pupils who have an early opportunity to interact with a broad audience of stakeholders will be better prepared later as citizens to debate and think about scientific issues with an open and critical mind considering what have been mentioned as typical RRI aspects such as the global and sustainable impact of research findings and innovations in which positive and negative consequences are balanced, societal relevance, and the importance of participatory design and co-creation with end users (Sutcliffe, 2011). Communicating and sharing ideas develops awareness and understanding among all participants. Preparing future citizens for their role as active and informed participants in RRI therefore requires emphasising the importance of communication and dialogue. In the Ark of Inquiry project this aspect is highlighted by including inquiry activities where pupils must interact with a range of stakeholders such as science centre staff, university researchers, teacher education pupils, and citizens/end users. For instance, pupils can be asked to write about inquiry activities and outcomes as journalists of science, hence seeking debate with others about research findings.

What is Inquiry?

Scientific inquiry is defined as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (*NRC*, 1996, p. 23). According to Bybee (1997), inquiry constitutes the heart of science as a discipline, and true scientific literacy cannot be achieved without employing inquiry skills. Although scientific inquiry has become very important for scientists and educators since 1960s, there is still not a definite consensus about a definition of inquiry learning in science education literature. Recently, different science educators define inquiry learning in terms and in combination of the following: "formulating questions" (Keys & Bryan, 2001; Zee, Iwasyk, Kurose, Simpson & Wild, 2001), "designing experiments" (Shimoda, White, & Fredericksen, 2001; Yerrick, 2000), "predicting outcome" (Songer, Lee & Kam, 2002), "gathering resource and data"(Byers & Fitzgerald, 2002), "analyzing data" (Donaldson & Odom, 2001), "transforming knowledge" (Bybee, 1997; Hamm & Adams, 2002), "hands on, minds on activities" (Crawford, 2000; Gibson & Chase, 2002), "communicating scientific arguments"

(Bybee, 1997), "process of discovery" (Schwab, 1964), "making decisions about actions" (Hmelo-Silver & Nagarajan, 2001) and "authentic scientific practice" (Cartier & Stewart, 2000; Edelson, 2001) (cited in Atar,2007).

Inquiry begins with gathering information through the use of human senses — seeing, hearing, touching, tasting, and smelling. Inquiry supports and encourages learner to question, conduct research, and make discoveries on their own experiences. The practice transforms the teacher into a learner with pupils, and pupils become teachers with us. Anderson (2002) states that inquiry is a good combination of learning, teaching, and doing science in a classroom and all components are interrelated with each other.

Appendix 8.14 Web-based materials for Scientists: Phases of inquiry that learners go through during their engagement of inquiry activities

Ark of Inquiry is a European funded project by the FP7 programme of the European Commission that involves 13 project partners from 12 countries. The overall aim of the Ark of Inquiry project is to create a "new science classroom", one which would provide more challenging, authentic and higher-order learning experiences and more opportunities for pupils to participate in scientific practices and tasks, using the discourse of science and working with scientific representations and tools.

As a scientist, your participation to Ark of Inquiry project is very meaningful and important to reach project objectives defined in the project. The platform that is developed within the project life time includes inquiry activities that are widely available across Europe. We expect that from your end you will act as one of the major supporters of this platform.

Further to the definitions about inquiry and inquiry learning that the Ark of Inquiry website entails, we elaborate here on each inquiry phase by describing the processes that take place during each phase of inquiry and illustrate how they are interconnected and relate to each other. These phases are described in five distinct dimensions: Orientation, Conceptualisation, Investigation, Conclusion, Discussion and seven sub-phases: Questioning, Hypothesis Generation, Exploration, Experimentation, Data Interpretation, Reflection, and Communication.

The following Figure illustrates the relations and connections among the different inquiry phases (Figure 1):

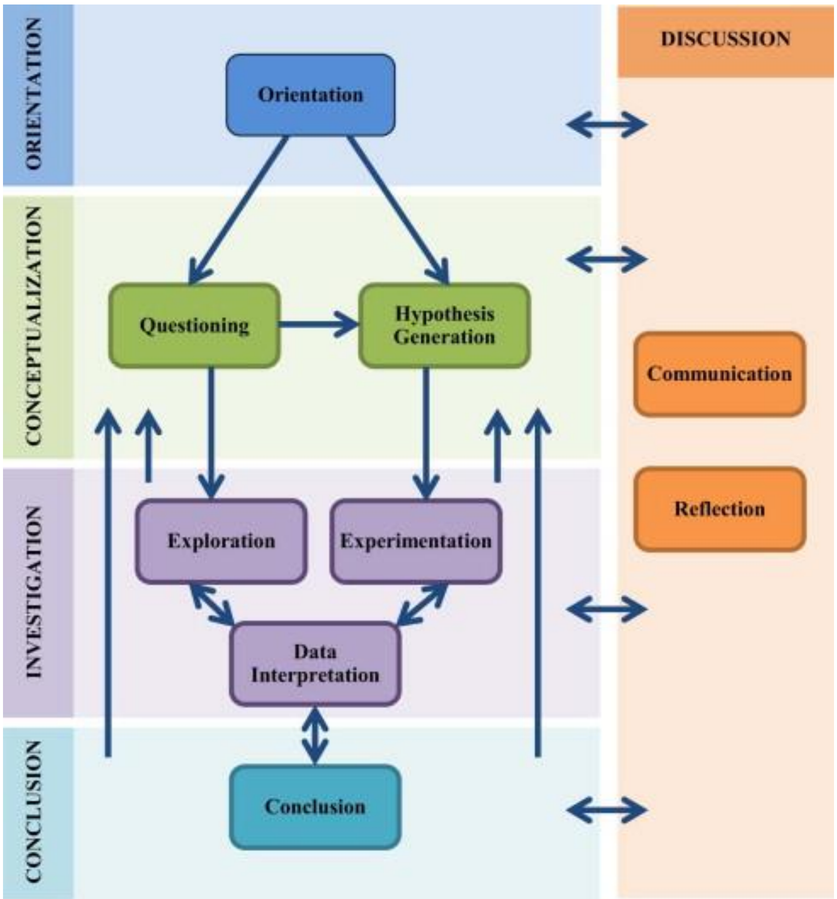


Figure 1. Inquiry learning framework [from Pedaste et al. (2015)].

Each phase of the inquiry learning framework is described below.

Orientation Phase: Orientation is a process to stimulate curiosity about a topic and leads to a problem statement. Curiosity is the "engine" of science education — it can be seen as the lever that drives pupils to keep learning, keep trying, and keep pushing forward. Hence, you, as a scientist, can aid in inspiring pupils' curiosity through sharing with them your scientific practices and expertise and also collaborate with science teachers in the Ark of Inquiry Platform.

Conceptualisation Phase: Pupils' engagement with the problem under study during the orientation phase will enable them to formulate their scientific research questions or hypotheses during the conceptualisation phase. Over the years, the answers to specific scientific research questions have led to important discoveries. In this phase, pupils consider what makes scientific research questions testable and then pose testable questions about problems they are studying. Consequently, it is important for pupils to acknowledge what counts as evidence that will be subsequently needed in answering their questions.

Investigation Phase: This phase entails a process of collecting empirical evidence to respond the research question or test the previously formulated hypotheses. Investigation phase is based mostly on hands on activities. It is a process of gathering empirical evidence to answer the research question or hypotheses. For example, the pupils work in groups in science laboratory to find evidence for the problem statement defined at conceptualisation phase. Investigation phase includes three sub-phases, which are exploration, experimentation and data interpretation.

Conclusion Phase: In this phase, research findings from investigation phase are reported and justified by the results of the investigation. Pupils are expected to present their data collection and interpretations through various ways such as presentations or reports, including theoretical evidence.

Discussion phase: This phase of inquiry is directly connected to all the other phases. It consists of communicating partial or completed outcomes, as well as reflective processes to regulate the learning process. Discussion phase includes two sub-phases: communication and reflection. The communication sub-phase generates support for scientific research or study, or to inform decision-making, including political and ethical thinking. The reflection sub-phase aims to meaningfully raise pupils' skills in developing creative, scientific problem-solving and socio-scientific decision-making abilities.

In terms of pathways through which inquiry unfolds, Figure 1 shows that inquiry is rarely a simple linear sequence. Various possible pathways exist and are indeed expected. Inquiry begins in the Orientation phase, but already in the next phase there is a choice to move through either the Questioning or Hypothesis Generation sub-phase. The difference relates to how familiar pupils are with the theory that underlies a topic. If pupils have little to no background then they should start with the Questioning sub-phase (which subsequently guides them to the Investigation phase via the Exploration and Data Interpretation sub-phases). After acquiring experience with the topic the pupils can return and select the Hypothesis Generation sub-phase. Alternatively, pupils with no familiarity with a topic could move from the Questioning to Hypothesis Generation sub-phase if they collect enough background information to formulate a specific hypothesis. In any case, Hypothesis

Generation is an important phase because it leads to the Experimentation sub-phase. Experiments usually form the most critical part of inquiry since it is through empirical testing that relationships between dependent and independent variables can be established. After the Investigation phase there is the Conclusion phase. A unique feature of the Pedaste et al. framework is that the Discussion phase is in continual connection with the other inquiry phases. The Discussion phase allows for communication and reflection at any time during inquiry.

Appendix 8.15 Web-based materials for Scientists: Skills and practices that are involved during inquiry learning

What does inquiry in a primary or secondary classroom mean? You as a scientist are used to domain-specific steps to take in doing your research. But can those steps be taken into any classroom as well? Although most scientists agree on inquiry being a cyclic process in which you go through different inquiry phases there is a lot of variation in what these phases are and how they are called. This is just the mix of variation that can really deprive teachers and pupils, as they are not experienced enough to see the overall similarities between those different models and processes. Scientists can move easily from one model of inquiry to the next because they can see their overlap. For teachers and pupils, however, looking at different models of inquiry may be a burdening task. What they need is one general model that encompasses other variations as well, so that they can stick to this general model when working on inquiry activities. Pedaste et al. (2015) tried to solve this problem by comparing and analyzing 32 articles describing inquiry phases resulting in five general inquiry phases that can be recognised in all (many) other models of inquiry. Below this general model of scientific inquiry is presented. For each phase, the skills involved are explicated and shortly illustrated with activities of pupils in a classroom. The general model of inquiry is summarised at the end of this web-based material in a table.

Promoting scientific inquiry in primary and secondary schools has three different purposes:

1. a cognitive purpose: we want pupils to learn to do inquiry;
2. a metacognitive purpose: we want to raise pupils' scientific awareness (SA) of inquiry as a process;
3. a societal purpose: we want pupils to learn to think about the relevance, consequences and ethics involved in science and scientific inquiry and want them to learn to think as responsible researrchers and innovators (RRI).

The first four phases focus on the development of both cognitive skills and metacognitive skills, whereas the last phase focuses on the development of a responsible attitude.

Skills and practices for each inquiry phase

Orientation

- *explore topic*
- *state problem*
- *identify variables*

The inquiry learning process starts with orientation during which pupils get an idea about the topic which is introduced by the environment, given by the teachers or defined by the pupil. Pupils' interest and curiosity for this topic is stimulated, they get more acquainted with the topic and the main variables are identified. The outcome of this phase is a problem statement which gives direction for the next phases (Pedaste, et al, 2015). Skills that need to be developed or stimulated with your pupils are curiosity, ability to explore a topic, to state problems and to identify variables that matter in their investigation.

The teacher opens the window and throws out a ball of paper. She waits for or asks the pupils to react (before she puts the paper in the wastebasket). By this introduction the teacher has started a discussion about environmental pollution, waste and preserving the earth. After the discussion she lets pupils search for information about the current situation regarding environmental pollution and what can be done to stop pollution. Pupils share their findings in a classroom mindmap. At the end of the lesson they present the mindmap and conclude that environmental pollution is a big problem and that every individuals (every pupils) behavior (independent variable) can contribute to preserving or polluting the earth/environment (dependent variable). The teacher asks her pupils do we know what we can do to help preserve the earth?

Conceptualisation

- *raise questions*
- *identify hypothesis*
- *research plan*

During conceptualisation, pupils should be provided with the opportunity to determine the key concept that will be studied during the inquiry, driven by either questioning or hypotheses (Pedaste et al., 2015). A pupil with less experience with the topic will first formulate questions based on the problem statement before moving on to hypotheses. Both of these should be based on theoretical justification and contain independent and dependent variables. Pupils learn to raise research questions and identify testable hypotheses. They also learn and practice to make a plan for their investigation necessary for answering the research questions or test the hypotheses. The outcomes of conceptualisation are research questions and/or hypotheses to be investigated and a research plan to answer these questions/hypotheses.

The teacher asks pupils to think of aspects they can change in their behavior and which contributions these changes would have in lessening environmental pollution. Each pair of pupils thinks of one thing they would change in the next two weeks and predict what outcome this will have. Josh and Steven always come to school by car and want to ride their bike to school the next two weeks. They formulate the question: What is the difference in CO2 discharge if we ride our bikes to school the next two weeks instead of driving by car? They also think that if they go to ride their bike to school every day, their classmates will follow their example which can lead to even less CO2 discharge. Therefor they also make the following prediction (Hypothesis). If we ride our bike to school every day for two weeks the CO2 discharge will become even less than our own car rides would produce because our classmates will start following our example. Josh and Steven make a plan for investigation They will ride their bike to school for two weeks, calculate what CO2 discharge they will not produce during this period of time by mixing information about the route to school and characteristics of their parents cars. They will ask their classmates after one week, and after two weeks if they have been using their bike more often to come to school instead coming by car, how much more and what is the reason for any change. For the classmates that have made a change because of them setting an example they will also make the same calculation as they made for themselves.

Investigation

- *collect data*
- *analyse data*
- *formulate findings*
- *SA: monitor*

The investigation phase follows the conceptualisation phase and is the phase where curiosity is turned into action in order to respond to the stated research questions or hypotheses (Scanlon et al., 2011). The first step is to collect data to find ansers to research questions and/or hypotheses. Pupils then move to data analysis by organising and interpreting their data. During the process of collecting and analysing it is important that pupils have the skills to systematically collect data, follow and monitor their research plan and make well-founded changes in this plan if necessary. Pupils learn to search for relevant information, systematically collect relevant data and organise their data in order to help them answer their research questions or test their hypothesis. During data analysis pupils learn to make meaning out of their collected and organised data and to compare and contrast their findings against each other, as well as against other findings. Gradually, they learn to synthesise findings and recognise patterns in their data that can be formulated into findings.

Josh and Steven have collected data following their plan. To show their results they have made 'before and after' tables regarding their own CO2 discharge and the CO2 discharge of their fellow pupils who also rode their bike to school. The outcomes of the interviews were clustered and counted.

They formulate as a finding that their own CO2 discharge has lessened with 0,395 ton. Three of their classmates have also chosen to ride their bike so they can ride with them to school. (0,689 ton CO2 less).

Conclusion

- *draw conclusions*
- *relate findings*
- *SA: evaluate*

In this phase the outcomes of the investigation phase are turned into main conclusions. By relating those findings to their reseach question(s) and/or hypotheses pupils learn to decide what these conclusions actually mean. During the conclusion phase, pupils learn the ability to infer the answers to their research questions or arguments for rejecting or supporting their hypothesis from their data (Pedaste et al, 2012). After reaching conclusions and answering the research question, the entire inquiry is critically evaluated in order to determine the solidness of the research findings.

Josh and Steven were able to answer their question 0,395 ton + 0,689 ton = 1.084 ton less.discharge in two weeks. They found their hypothesis supported by their findings but also learned during their interviews that 12 more pupils started to ride their bike not because of their example but because of the schoolproject. These pupils were not part of their research but did surface in their investigation. Josh and Steven conclude that a school project might have a bigger impact then setting the example, they regret not involving this variable.

Discussion

- *RRI: relevance*
- *RRI: consequences*
- *RRI: ethics*

On the one hand, the discussion phase can be seen as an ongoing process related to all other inquiry phases involving communication about and reflection and discussion on the process and outcomes of the inquiry along the way (Pedaste et al., 2012). On the other hand, when the actual inquiry is finished it is time to communicate to a wider audience on the relevance, consequences, and ethics of those findings. In this last phase, therefore, special interest is paid to learning to reflect on, communicate and discuss their inquiry activities and findings to peers, teachers, and society. For the purpose of communication, pupils learn to share research findings by being able to articulate the own understandings of the research answers or hypotheses. They also learn to listen to others sharing their findings or commenting on yours. To communicate well, pupils must be able to reflect on (specific parts of) their inquiry and point out the relevance, consequences and ethical issues related to it. They need to be able to receive and provide feedback, and by doing so become part of a community of inquirers that encompasses ongoing discussion fed by scientific research.

Josh and Steven present their findings to their classmates and listen to the presentations of their peers. They receive and give feedback on research processes and outcomes. They answer questions and give arguments for their choices. Together with their peers they formulate the relevance and consequences of their joined findings. What can be learned about human behavior and environmental pollution based on all research projects? After this they talk about what more they can do to communicate about their findings to others but decide that they first have to do more research within bigger groups to be sure that they can inform and advice others based on their findings.

Table 1. Skills and Examples of the Phases of Inquiry Learning

Inquiry phase	**Skills**	**Examples**
Orientation	Explore topic	Find out what is the current situation on environmental pollution
	State a problem	We don't know what we can do to preserve the earth
	Identify variables	Human behavior (independent) & Environmental pollution (dependent)
Conceptualisation	Raise questions	What is the difference in CO2 discharge when we ride our bike to school?
	Identify hypothesis	The difference in CO2 discharge will be more than our own expected discharge because our classmates will follow our example
	SA: Research plan	We will calculate the difference in CO2 discharge
Investigation	Collect data	Interview fellow pupils and make calculations
	Analyse data	Table shows CO2 discharge before and after
	Formulate findings	1.084 ton less.CO2 discharge in two weeks
	SA: Monitor	Follow research plan and make well-grounded changes when needed
Conclusion	Draw conclusions	We were able to decrease the CO2 discharge by riding our bikes and our friends who followed our example
	Relate findings	If we want to decrease CO2 discharge a school project has more effect then setting the example
	SA: Evaluate	Next time it would be interesting to investigate the results of a school project about pollution on the CO2 discharge
Discussion	RRI: Relevance	Steven tells his classmates that they should organise a school campaign to persuade more pupils to ride their bike to school based on the outcomes of their research
	RRI: Consequences	Josh tells in his presentation that his research results are important because they show that everyone can make a difference in preserving the earth by making small changes in their habits
	RRI: Ethics	Josh says to Steven that they cannot oblige their fellow pupils to ride their bike based on this research alone

Each skill matching the phases of inquiry described in table 1 have different proficiency levels described from A-level (Novice) to C-level (Advanced) in the evaluation system of the Ark of Inquiry.

Appendix 8.16 Web-based materials for Parents

Right below we provide the content of the web-based materials for Parents as they appear on the Ark of Inquiry website [see www.arkofinquiry.eu/parents].

Dear parents,

The materials provided here aim to inform you about the project *Ark of Inquiry: Inquiry Activities for Youth over Europe.* This project aims to give you the opportunity to follow your child on the exciting journey of exploring scientific questions, draw evidence-based conclusions and to get an insight on real scientific challenges. In the platform of *Ark of Inquiry* you can find stimulating ideas and supporting materials that will help you in fostering your child's scientific way of thinking.

In the context of Ark of Inquiry project, your role is considered essential in facilitating your child's engagement in inquiry activities. To enhance your role and contribution towards this direction, we developed several web-based materials that will help you familiarize yourself with:

- background information about the outline of the Ark of Inquiry project,
- what is scientific inquiry through an example of an inquiry activity,
- how to support your children at home.

Appendix 8.17 Web-based materials for Parents: Background information about the outline of the Ark of Inquiry project

The Ark of Inquiry project aims to raise youth's awareness, by bringing together different aspects of the relationship between sciences and innovations, such as ethics, gender equality, or science education. Young European citizens between the age of 7 and 18 will be provided with a variety of engaging inquiry activities to improve their inquiry skills. The project enables students to keep track of their inquiry skills development and to improve them independently from teachers and parents. This is achieved by providing appealing inquiry activities via the Ark of Inquiry web-based platform for pupils to work on, and for parents to find help for supporting their children at home. You simply need to register with the platform to gain access to the materials provided.

Once this is done, students will be able to conduct inquiry activities at their leisure. In doing so, first their current inquiry skills will be assessed automatically and recorded. Based on this, working on further activities will increase their inquiry skills while their progress will be recorded as well.

In the course of the project, the students with the highest achievements will be rewarded with Inquiry Awards. The relative scale is similar to international Olympiads where there is a fixed ratio of gold, silver and bronze medals. So there is another motivation for the students to develop inquiry skills.

Appendix 8.18 Web-based materials for Parents: Explaining what is scientific inquiry through an example of an inquiry activity

The experience from domestic activities can foster the development of better understanding of chemistry, biology, physics, math and other important subjects we aim to promote at school.

So how you can help your child to approach, for example, the baking of a cake from the perspective of inquiry?

STEP 1 - Forming scientific questions and hypotheses

Firstly, you can work together with your child to respond to the following question: “What kind of cake would you like to bake?”

If you already identified the type of the cake you would like to bake, you can proceed in responding to the next question: “What kind of ingredients will you need?” Make a list of needed ingredients together with your child. Next, it is time to form a **scientific question**. For example: “What is the importance of every single ingredient that is used for baking the cake? Will there be any difference if I left behind the addition of a specific ingredient?”

You also can discuss and write down your possible scenarios to the paper, to compare the results later.

What is the difference between posing a question or telling how to do?

Most parents feel the need to answer their children’s questions as precisely as they can, as naturally they have the urge to help and support their children and make life easier for them. However, this might lead the children to depend on their parents for help and to provide them with easy ready-made answers whenever they encounter a problem. Moreover, it will prevent the children from developing their own problem-solving skills, as it will lead to an accumulation of factual knowledge that might be meaningless for the children. It is important to raise students’ interest in answering their own questions. The best questions are those that relate to children’s interests that they themselves would like to extend their learning on a specific subject. Also, a “good” question is considered the one that can be answered through research in natural sciences.

STEP 2 – Planning and realization of an investigation

Now it is time to think about, how it is possible to find out, and what is the impact of of the different ingredients that are used for baking the cake. Give your child the opportunity to propose the steps that should be followed for answering the research question, and help him/her understand what should be varied and what should be constant while baking several cakes to compare the impact of a specific ingredient to the baking of the cake. For instance, if you want to test whether the *baking powder* affects the baking of a cake, then it is important to help your child understand that for answering this question you need to bake two cakes that will differ only in the addition of the baking powder (e.g., one should contain baking powder and one without baking powder), while all the rest of ingredients and external variables (e.g. heating temperature, size and type of the baking pan, time of baking, etc) should remain the same for both cakes. At the end of the experiment, it is important to help your child decide if the addition of the baking powder influenced the baking of the cake and provide evidence to support his/her conclusion.

Why it is important to search the evidence?

Encourage your children to reason with evidence that derives from the experiment being performed rather than posing mere guesses and unsupported assumptions. The concept of evidence has a central role in scientific research. Basically, if there is no evidence for something, it does not exist or is not true, respectively. But what is scientific evidence? Evidence helps to reinforce your question, or more scientifically, your hypothesis. With enough evidence the answer you are formulating becomes trustworthy and robust. It is also important to collect evidence from a variety of sources. In our example it is not enough to bake one cake. If we need to know what is the role of baking powder, we should bake also the cake without baking powder.

STEP 3 - Analysis and reflection of the data

Now the cakes are ready and we can see the results. What we can tell about the cakes? What we could test?

a) *How does it look like?*
b) *How does it taste?*
c) *Something else….*

What kind of conclusions can we make? What is the actual role of the baking powder?

How can you do this with your child? It is a very crucial aspect of scientific thinking. You have to start with the initial question and see, if your data can be used in answering your questions or not. Maybe you have to change form of representing the data, from a table to a graph for example, to make the "outcome" more visible for your child. When thinking of the experiment, the following questions will help you to structure this step. For the planning and executing try to find answers to the following questions:

- …concerning the correct strategies of experimentation
- …concerning strategies of variable control
- …concerning strategies of data analysis

The next sub-step is to think about the complete process, and to the examine elements that are transferable to other situations. It is a difficult step, and a lot of pupils, and of course most of the children, stop thinking about the problem once they solved it. They become not explicitly aware about the mechanism and the meaning of problem solving process. What were the factors that lead to success? Why did I fail? As a result, they have to start from the beginning when they try to solve a similar problem in a context, only a little bit different from the first one. But you can help your child to get one step further! Try to discuss with him/her for example the following aspects explicitly …

- …about application or transfer of the tasks
- …about possible sources of experimental errors
- …about enhancement of experimental setting

Appendix 8.19 Web-based materials for Parents: *How to support your children at home?*

The Ark of Inquiry project focuses on engaging the students in inquiry activities during designed instruction by their teacher. The teacher will get a special training for this instruction. Once they have developed their inquiry competence the students will be able to work independently with the activities that will be provided through the platform. You, as parents have the important role of guiding and motivating your children in conducting their inquiry activities.

Most parents feel the need to answer their children's questions as precisely as they can, as naturally they have the urge to help and support their children and make life easier for them. However, this might lead the children to depend on their parents for help and to provide them with easily accessible answers whenever they encounter a problem. Moreover, it will prevent the children from developing their own problem-solving skills and lead to an accumulation of factual knowledge at best.

Raising students' science awareness is the aim of this project. You as parents can help and guide your children in conducting their inquiry activities so that your children can improve their science awareness. A situation in which inquiry learning can be realised is characterized by five essential features (NRC 2000, p. 24):

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

A variety of pedagogical frameworks are used to "transfer" these features into teaching strategies for science classrooms, and a lot of research is carried out to evaluate the effectiveness of different instructional models. Most approaches have in common, that learning by inquiry is a cycle. Once the student has found an answer, a new question arose upon the result. The easiest way for you to support your child at home is to take the following three steps into account. They summarise the key features and make inquiry learning easy to adapt at home.

4.4.1. Posing questions

Posing questions is an important starting point in the inquiry cycle. This is a worthy and crucial activity for students to engage with. What are the characteristics of the questions that we would like to answer in the context of inquiry?

The first important characteristic of a question is the topic of the question. It is important that students are genuinely interested in answering questions. If they do not care about the questions they will not be interested in doing the work to answer them. The best questions are about things children actually want and need to know about. For example:

- What are bubbles in mineral water make of?
- What factors influencing the growth of a plant?
- Why does lemon juice prevent the brown coloring of fresh peeled apples?

Another important element that makes a question worth of dealing with is whether the question can be answered through research and not by merely guessing its response. It is important to keep in mind that some questions are unanswerable; for instance, the question about the number of sand grains in the world is not a question that neither can be answered or merits of research interest. The format and nature of the questions should enable your children to follow a feasible path for answering them.

The third point that you have to consider is the clarity of the formulated question. Not only for you but also for your children. If it is confusing, check whether your question refers to more than just one theme (e.g., the question "Does soil, sun, and water affect plant growth?" entails three variables that cannot be tested at the same time). If a question entails two themes at the same time, break it into two questions that each can be tested individually.

Consider the following as an example of a good formulated question: *What is the effect of the amount of baking powder on a cake?* As parents you often bake cakes, quite often children participate during this task. So it can be an interesting question for you, too. The question can be answered through research, because you have everything for conducting a research in your own house and with different amounts of baking powder you can answer this question. Also the question is clear and includes only one variable, i.e., the amount of baking poweder.

After posing a question in a more every day style, try to develop this question into a scientific one. Identify the dependent and independent variables, and make a prediction of the effect. Which factor is influencing the result? A statement like this is called *hypothesis*. For the above example, with the effect of baking powder the hypothesis could be: The baking powder makes the cake to "rise". This hypothesis be tested following the scientific method. You can plan an experiment that entails baking two cakes that differ only in the addition of baking powder (e.g., only one of the cakes contains baking powder), while the rest of the ingredients must be the same, and of course the baking conditions (temperature, time, …) must be for both cakes exactly the same.

4.4.2 Searching for evidence

The concept of evidence is considered as one of the central aspects of scientific inquiry. Basically, if there is no evidence for something, it does not exist or it is not true, respectively. But what is scientific evidence? All types of observations and measurements that can be collected from a phenomenon under study are considered as evidence. Evidence helps to reinforce your hypothesis. With enough evidence you can answer your question. So it is important to collect evidence from a variety of sources. In our example, it is not enough to bake one cake with a certain amount of baking powder. Only after using different amounts of baking powder in several cakes you can collect enough evidence to prove your hypothesis and answer your question.

Encourage your children to reason with evidence that can be proven rather than accepting guesses and assumptions. If your arguments are falsified, think about your hypothesis and look for evidences that will help in confirming or rejecting your hypothesis.

4.4.3 Finding relevant equipment for experimentation

Another type of support for your children is to create a *scientific environment* at home. It is possible to explore some of the principles of science in your kitchen. In the Ark of Inquiry project a platform is developed which offers carefully selected inquiry activities easily be done at home with everyday materials. Also there are a lot of sites in the Internet with experiments you can do with your children at home, e.g.:

- http://tinkering.exploratorium.edu/projects
- http://www.science-sparks.com/2013/04/27/kitchen-science-round-up/
- http://foodscience.psu.edu/youth/youth
- http://www.sciencekids.co.nz

If you are interested in learning a little bit more about the competencies of scientific thinking at different age stages of your child, please visit the following link: http://www.kidspot.com.au/schoolzone/Science-experiments-Science-experiments-for-kids+4372+314+article.htm