Web-based materials for Teacher Educators/Researchers

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.

Ark of Inquiry

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.

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.

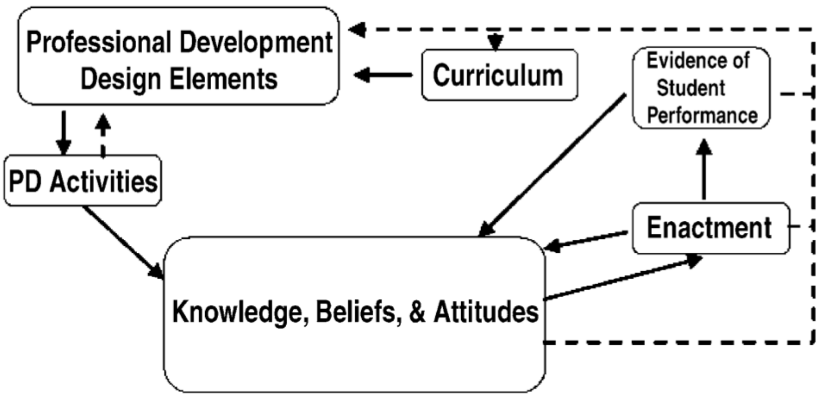
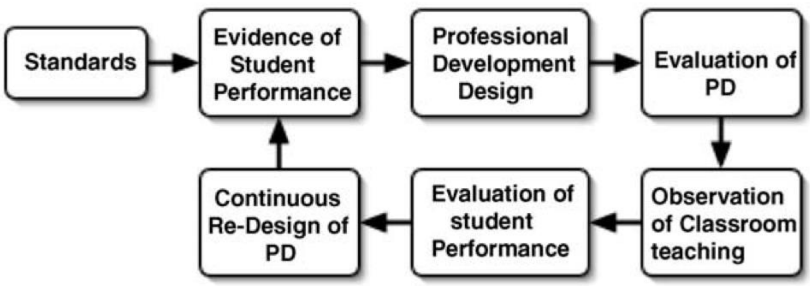
Table 1. Characteristics of effective professional development (adapted from Capps et al., 2012, pp. 296 - 297)

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.

Reference	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.
3. A dynamic model of teacher learning	
Model or Framework	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)
Aims	"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)
Outline of the professional development course (PDC)	 Fig. 2. Iterative model for the evaluation of professional development. (p. 648)
Outcomes	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

	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

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

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.

Online Questionnaires

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.					

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.					

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.

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 observations and inferences of the natural world. Scientists use their imagination and creativity throughout their scientific investigations.	1I (+); 4A(+); 4B(+); 4C(+); 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(-)

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	Investigation of electricity	Stories of scientists and their work	Movement of plants	Investigation 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 measurements and observations	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 investigations	Design simple, but full, investigations	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 demonstrated in the work of scientists	Develop the ability to reason using logic and evidence to form an explanation	Understand 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

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.

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

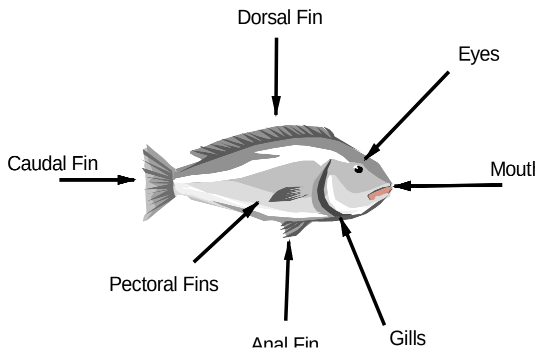
Exemplar items

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.

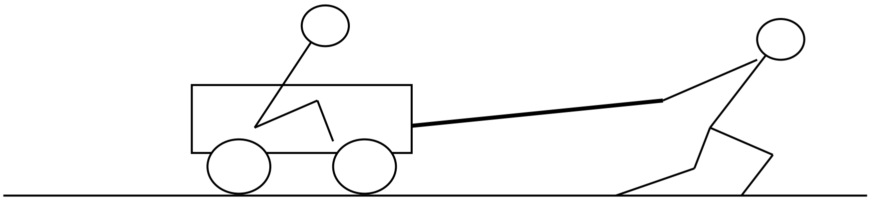
Response “A” and “B” align only with knowledge-level objectives, whereby the intent is for students to know the vocabulary. Knowing formal names of body parts is not a necessary criterion for associating form and function and the approach is not inquiry.

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.

<u>Comments on Example Item 2</u>

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.

Open-ended assessment instruments

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?

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.

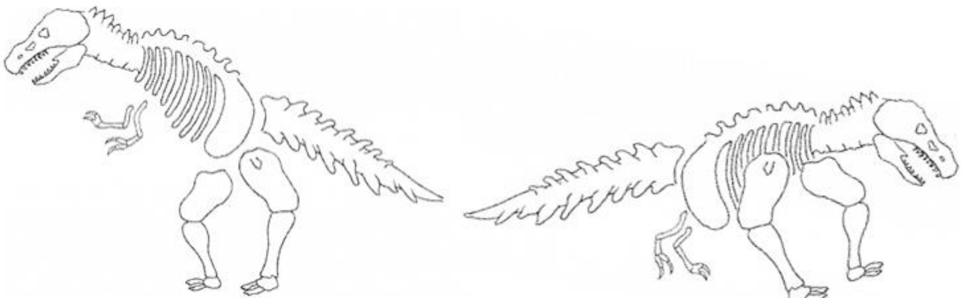
Minutes of light each day	Plant growth-height (cm per week)
0	25
5	20
10	15
15	5
20	10
25	0

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.



Skeleton 1 or Skeleton 2

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?

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.

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.

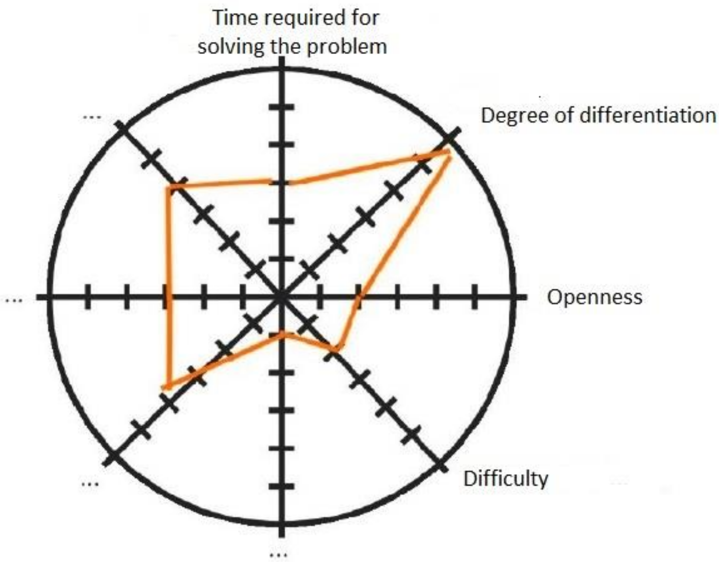
When to use: it is best to introduce during a teacher training, and then teachers can use it independently.

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).

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[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.

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		

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.

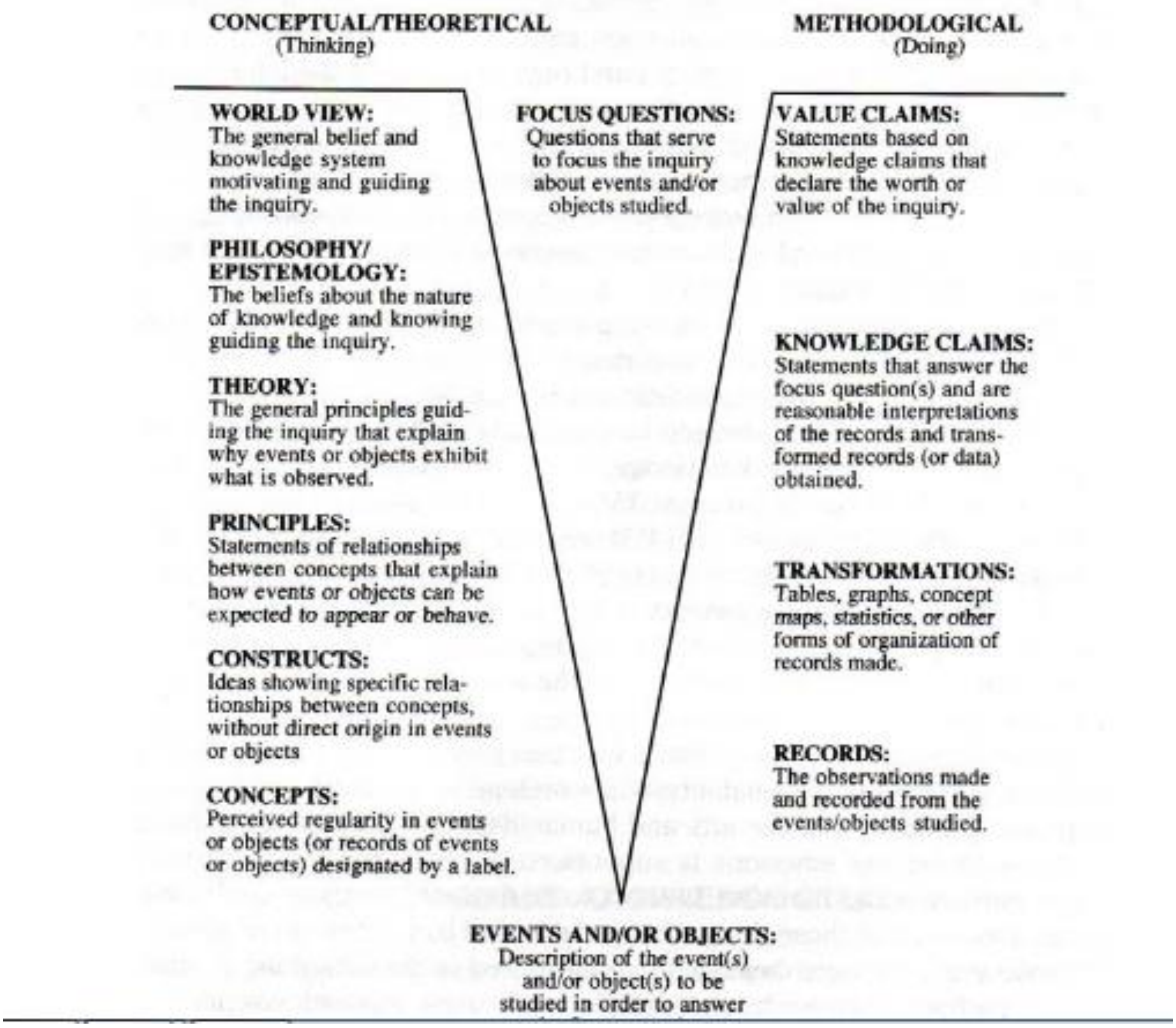
When to use: it is best to use during the teacher training or for mentoring teachers.

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.

[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)

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

<table>
<tr><td>School:</td><td></td></tr>
<tr><td>Teacher:</td><td></td></tr>
<tr><td>Class:</td><td></td></tr>
<tr><td>Subject:</td><td></td></tr>
<tr><td>Date:</td><td></td></tr>
<tr><td>TARGET:</td><td>☐ pilot
☐ trial
☐ adaptation</td></tr>
<tr><td colspan="2">I see the following opportunities in my class/ group / with my students in science education:
I decided to work with the task…
Title:

Emphases:</td></tr>
<tr><td colspan="2">I would like to reach the following with my work …
Goals:
Objectives:</td></tr>
<tr><td colspan="2">I would like to use it in he following ways:
☐ Individual support (talent care/…):
☐ Group-work, community building:
☐ Differentiation:
☐ …………………………………………..</td></tr>
<tr><td colspan="2">How are the steps of inquiry cycle represented in the activity?
□ Orientation:
□ Conceptualisation:
□ Investigation:
□ Conclusion:
□ Discussion:</td></tr>
<tr><td colspan="2">My teaching aims related to inquiry learning:
□ Problem-based thinking:
□ Experimenting, hands-ons:
□ Students’ autonomy:
□ Communication (presentation, argumentation, etc.):</td></tr>
</table>

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:

□ ………………………………………………..

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)?

Interview protocols

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.

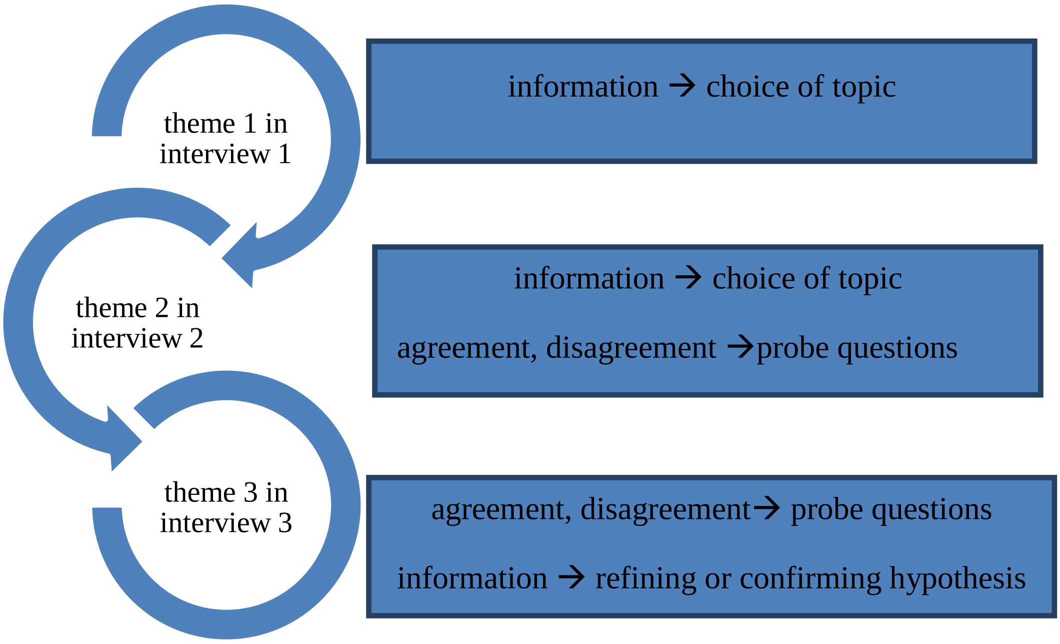
(2) *An iterative process similar to or supporting action research*. Although convergent interviewing does not seem at first to be really participative, but due to its cyclic nature and its use of dialectic, it may constitute an action research cycle too, which might be very useful in the development 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.

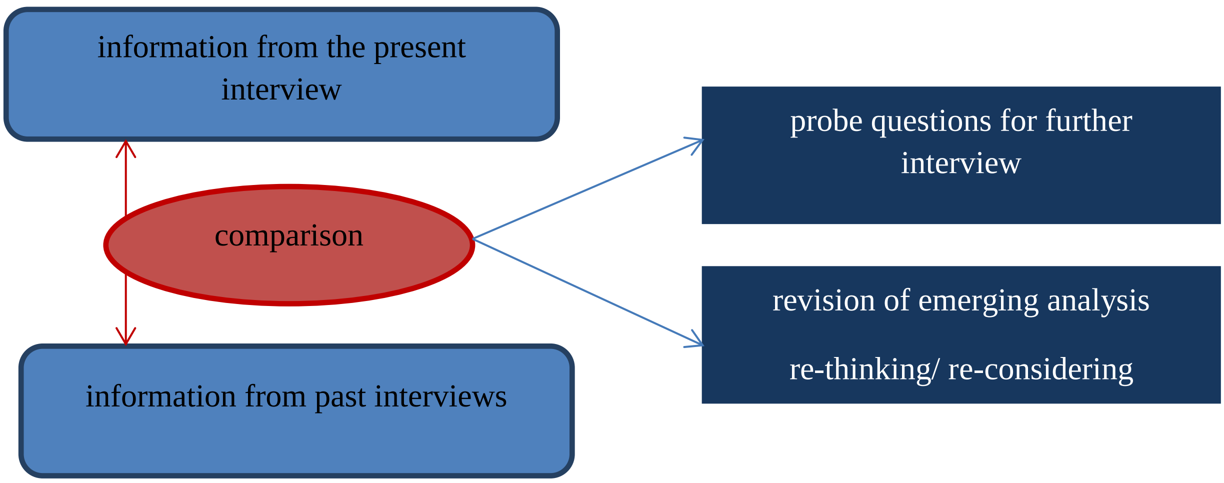
6. Inviting a summary

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.

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

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?		