

Web-based materials for Scientists

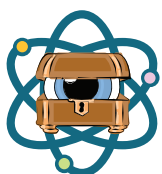


Dear scientist,

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

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

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



Ark of Inquiry

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

What is Responsible Research and Innovation (RRI)?

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

The Ark of Inquiry project aims to foster RRI by teaching pupils core inquiry skills needed to evaluate the credibility and consequences of scientific research and by offering opportunities for pupils to engage with different societal actors involved in the research and

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

What is Inquiry?

Scientific inquiry is defined as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (NRC, 1996, p. 23). According to Bybee (1997), inquiry constitutes the heart of science as a discipline, and true scientific literacy cannot be achieved without employing inquiry skills. Although scientific inquiry has become very important for scientists and educators since 1960s, there is still not a definite consensus about a definition of inquiry learning in science education literature. Recently, different science educators define inquiry learning in terms and in combination of the following: "formulating questions" (Keys & Bryan, 2001; Zee, Iwasyk, Kurose, Simpson & Wild, 2001), "designing experiments" (Shimoda, White, & Fredericksen, 2001; Yerrick, 2000), "predicting outcome" (Songer, Lee & Kam, 2002), "gathering resource and data"(Byers & Fitzgerald, 2002), "analyzing data" (Donaldson & Odom, 2001), "transforming knowledge" (Bybee, 1997; Hamm & Adams, 2002), "hands on, minds on activities" (Crawford, 2000; Gibson & Chase, 2002), "communicating scientific arguments" (Bybee, 1997), "process of discovery" (Schwab, 1964), "making decisions about actions"

(Hmelo-Silver & Nagarajan, 2001) and "authentic scientific practice" (Cartier & Stewart, 2000; Edelson, 2001) (cited in Atar,2007).

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

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

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

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

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

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

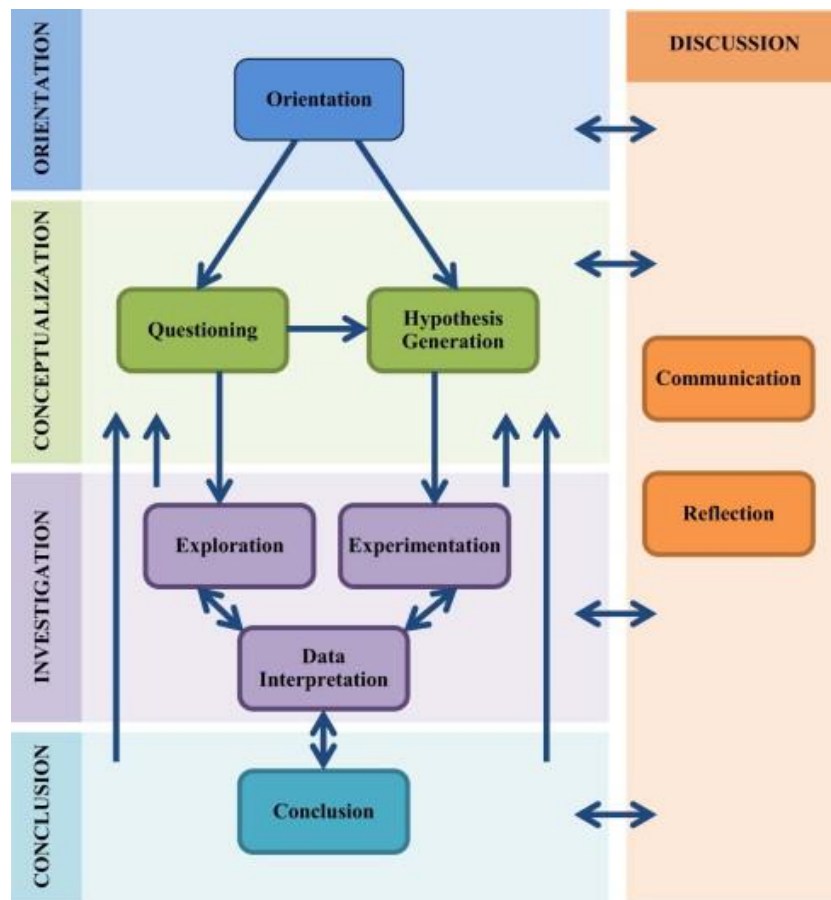


Figure 1. Inquiry learning framework [from Pedaste et al. (2015)].

Each phase of the inquiry learning framework is described below.

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

Conceptualisation Phase: Pupils’ engagement with the problem under study during the orientation phase will enable them to formulate their scientific research questions or hypotheses during the conceptualisation phase. Over the years, the answers to specific scientific research questions have led to important discoveries. In this phase, pupils consider

what makes scientific research questions testable and then pose testable questions about problems they are studying. Consequently, it is important for pupils to acknowledge what counts as evidence that will be subsequently needed in answering their questions.

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

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

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

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

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

Skills and practices that are involved during inquiry learning

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

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

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

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

Skills and practices for each inquiry phase

Orientation

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

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

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

Conceptualisation

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

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

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

Investigation

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

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

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

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

Conclusion

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

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

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

Discussion

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

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

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

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

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

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