Web-based materials for Teachers

Dear teacher,

in the context of the Ark of the Inquiry project, you are one of the fundamental stakeholders, who will play a key role in helping pupils engage in inquiry activities. To enhance your role and contribution towards this, we have developed several web-based materials that will help you familiarise yourself with

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

Ark of 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 in the 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 participate 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. 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 students, and citizens/end users. For instance, pupils can be asked to write about inquiry activities and outcomes as journalists of science, hence seeking debate with others about research findings.

What is Inquiry?

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

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

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

Further to the definitions about inquiry and inquiry learning that the Ark of Inquiry website entails, we elaborate here on each inquiry phase by describing the processes that take place during each phase of inquiry and illustrate how they are interconnected and relate to each other. These phases are described in five distinct phases, Orientation, Conceptualisation, Investigation, Conclusion, Discussion, and their 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).

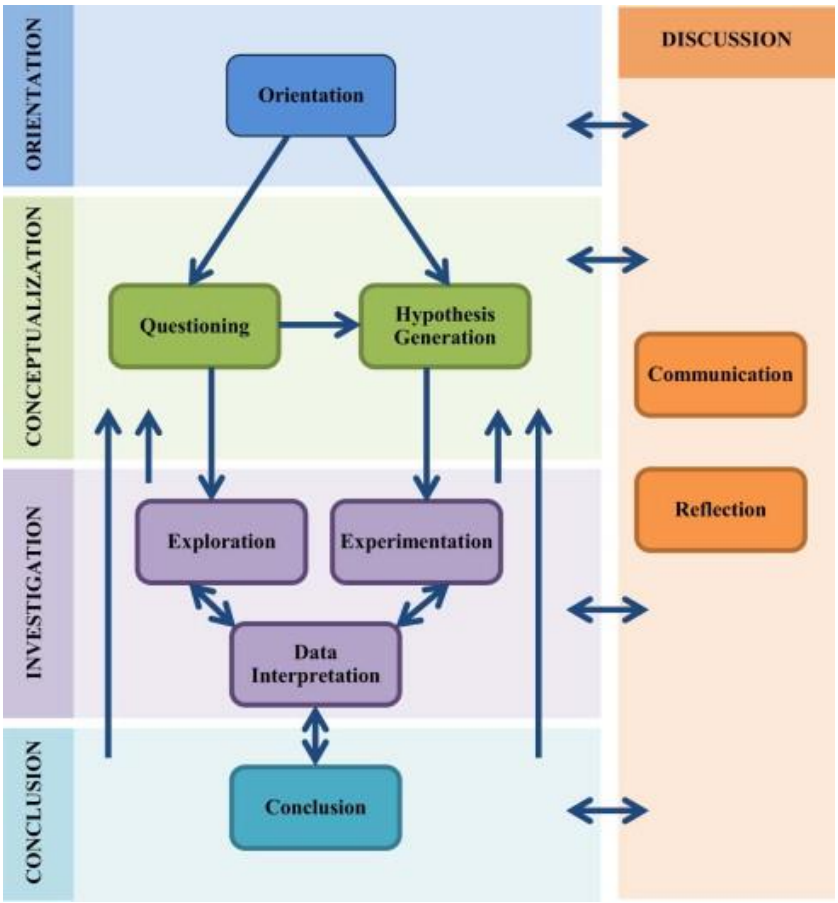

Figure 1. Inquiry learning framework [by Pedaste et al. (2015)]

Each phase of the inquiry learning framework is described below.

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

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

Investigation phase: The Investigation phase is based mostly on hands-on activities. It is a process of gathering empirical evidence to answer the research question or verify hypotheses. For example, pupils work in groups in a science laboratory to find evidence for the problem statement defined in the Conceptualisation phase. The Investigation phase includes three sub-phases: Exploration, Experimentation, and Data Interpretation.

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

Discussion phase: This phase of inquiry is directly connected to all the other phases. It consists of communicating partial or completed outcomes as well as reflective processes to regulate the learning process. The Discussion phase includes two sub-phases:

Communication and Reflection. The Communication sub-phase generates support for scientific research or study, or serves the purpose of informing 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.

How does an inquiry-based curriculum look like?

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

''Boiling and peeling eggs''

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

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

Next, the learners are supported in developing hypotheses that derive from their

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

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

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

Level A

In the first experiment, the investigative question "Does the egg's age affect the boiling and peeling of eggs?'' is given in order for all groups of pupils to conduct the same experiment. Initially, learners are prompted to suggest a controlled experiment for answering the given investigative question without receiving any scaffolds on how to perform this task or feedback on their experimental design proposal, since the purpose of this activity is to enable the elucidation of learners' prior conceptions and level of skill acquisition about the design of controlled experiments. Next, the learners are engaged in a structured activity sequence through which they are scaffolded in identifying the variable that needs to be varied in their experiment (i.e. the age of the eggs), the variables that need to be kept constant, and the variable that has to be measured (i.e. the boiling and peeling of eggs). For each of the identified variables, the learners are prompted to specify how this would be treated for the purposes of their experimental design. For instance, for the peeling variable, the learners are expected to describe a procedure through which the peeling percentage can be measured. As soon as each group of pupils finalises their experimental design and receives feedback from the instructors, they make a prediction (e.g., what is the anticipated outcome of the experiment) and a hypothesis (e.g., provide an explanation to justify their prediction) based on the investigative question, and then they proceed in performing their

experiment. In doing so, they are expected to choose two eggs of different ages (e.g., a 3-day egg and a 15-day egg), keep all other variables constant for both eggs (e.g., the eggs' mass and volume, both eggs should originate from the same hen, the same volume of water for each egg, etc.), and after boiling and peeling both eggs, they should record data about the peeling percentage of each egg. At this stage, the learners plot their data using the most appropriate means for their representation (e.g., a line graph, a bar chart, etc.) and are prompted to interpret their data in relation to their investigative question and verify whether their predictions and hypotheses are confirmed or rejected.

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

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

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

Levels B and C

The structure of activity sequence described for Level A is repeated for Level B (advanced inquiry) and Level C (expert inquiry), during which learners choose new investigative questions and subsequently design and conduct new experiments. The difference between each level lies in the type of supports and scaffolds that learners receive throughout the curriculum. Specifically, during Level B, learners are asked to formulate the investigative question they are about to test themselves, and then they are provided with a table in

which they have to define the variable that should be tested, the variables that should be kept constant, and the variable that should be measured. For each of the variables they are asked to define and specify the ways they will manipulate the variables during performing their investigation. They are also asked to formulate a hypothesis and subsequently a prediction, based on their investigative question. For each of these tasks, the learners are given certain hints that point to specific activities that were implemented at a prior stage in the curriculum during Level A in case they need help in performing a specific task or refreshing what they have already learned during Level A. During working at Level C activities, learners are asked to formulate a new investigative question and decide what to do for answering it. They are provided with enough space to organise their work in a similar manner they were instructed to do during Level A and Level B activities.

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

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

Skills and practices involved during inquiry learning

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

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

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

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

Skills and practices for each inquiry phase

Orientation

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

Inquiry starts with Orientation, during which pupils get an idea about the topic which is introduced by the environment, given by the teacher or defined by the pupil. Pupils' interest in and curiosity about 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 to the next phases (Pedaste et al., 2015). Curiosity and the ability to explore a topic, state problems and identify variables that matter in their investigation are the skills that need to be developed or stimulated in your pupils.

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

The teacher opens the window and throws out a ball of paper. She waits for or asks the pupils to react (before she puts the paper in the wastebasket). By this introduction the teacher has started a discussion about environmental pollution, waste and preserving the Earth. After the discussion she lets pupils search for information about the current situation regarding environmental pollution and what can be done to stop pollution. Pupils share their findings on a classroom mindmap. At the end of the lesson they present the mindmap and conclude that environmental pollution is a big problem and that each individual's (each pupil's) behaviour (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 inquiry learning, driven by either questioning or hypotheses (Pedaste et al., 2015). A pupil with less experience with the topic will first formulate questions based on the problem statement before moving on to hypotheses. Both of these should be based on theoretical justification and contain independent and dependent variables. Pupils learn to raise research questions and identify testable hypotheses. They also learn and practice to make a plan for their investigation necessary for answering the research questions or test the hypotheses. The outcomes of Conceptualisation are research questions and/or hypotheses to be investigated and a research plan to answer these questions/hypotheses.

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

The teacher asks pupils to think of aspects they can change in their behaviour 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 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 bikes to school for two weeks and calculate the 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 bikes more often to come to school instead of coming by car, if yes, then how much more, and what the reason for any change could be. For the classmates that have made a change because of them setting an example, they will also make the same calculation they made for themselves.

Investigation

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

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

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

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

They formulate as a finding that their own CO2 discharge has lessened by 0,395 ton. Three of their classmates have also chosen to ride their bikes to school (0,689 ton less CO2).

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 cycle is critically evaluated in order to determine the solidness of the research findings.

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

Josh and Steven were able to answer their question: 0,395 ton + 0,689 ton = 1.084 ton less discharge in two weeks. They found their hypothesis supported by their findings but also learned during their interviews that 12 more pupils started to ride their bikes not because of their example, but because of the school project. 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 an example, and they regret not involving this variable.

Discussion

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

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

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

Josh and Steven present their findings to their classmates and listen to the presentations of their peers. They receive and give feedback on research processes and outcomes. They answer questions and give arguments for their choices. Together with their peers, they formulate the relevance and consequences of their joint findings. What can be learned about human behaviour and environmental pollution based on all research projects? After this, they talk about what more they can do to communicate 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 advise others based on their findings.

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

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

		pupils to ride their bikes to school based on the outcomes of their research
	RRI: Consequences	Josh tells in his presentation that his research results are important because they show that everyone can make a difference in preserving the Earth by making small changes in their habits
	RRI: Ethics	Josh says to Steven that they cannot oblige their fellow pupils to ride their bikes based on this research alone

Each skill matching the phases of inquiry described in Table 1 has different proficiency levels described from A-level (novice) to C-level (advanced) in the evaluation system of the Ark of Inquiry.

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

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

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

		explored during inquiry. As their investigations progress, prompt pupils to revisit their initial concept maps to integrate new information with previous understandings. This is a fruitful way to make pupils aware of the development of their conceptual understanding. • Provide adequate time for pupils to puzzle through the given problem. • By the end of the Orientation phase, make sure that pupils can describe the problem that has been presented in their own words and prompt them to state the driving question that departs from the problem description. A driving question entails "a need to know" and guides pupils through inquiry to find solutions to a question. The rationale for engaging pupils in defining a driven question departs from the notion that such an activity enhances and maintains pupils' interest, directs them toward their investigation goals and addresses authentic concerns. The driving question will help pupils during the following phase (Conceptualisation), in which research questions or hypotheses will be formulated.
CONCEPTUALISATION *The process of stating theory- based questions and/or hypotheses*	Questioning *The process of generating research questions based on the stated problem*	• Provide scaffolds to pupils for them to formulate their own research questions. Through these scaffolds, make pupils aware of ○ why a research question is needed at this stage, ○ what the syntax of a question that can be tested later is, ○ how a research question/investigative question differs from common-use or open-ended questions ○ how an investigative question and a hypothesis relate and differ (for hypothesis see right below)

		• Since pupils might not be familiar with the syntax of an investigative question, use the following heuristic: ask them to fill in the blanks in a given investigative question in which the independent and dependent variables are missing. An example would be "Does the…… affect the …….? After pupils have correctly completed the blanks with the variables that they need to test later, it is important to inform them that any investigative question follows the same format and always has two variables (the one that will be varied and the one that will be measured during the experiment) that are connected through the verb "affect". In a later stage, when pupils are about to test the effect of a new variable on the dependent variable, it would be useful to ask them to formulate the investigative question themselves, without providing its syntax, and if they fail to formulate it correctly, prompt them to visit to the previous investigative question, study its format and apply it to the new case. This way, the scaffolding of formulating an investigative question is faded out when pupils are comfortable with formulating the research questions on their own.
	Hypothesis generation *The process of generating hypotheses regarding the stated problem*	Hypothesis generation can precede or follow the formulation of investigative questions. It is important at this stage to keep in mind that in science, the term «hypothesis» is used differently than it is used in everyday language. In everyday language, the term is used to denote an educated guess or an idea that we are quite uncertain about. In science, on the other hand, «a hypothesis is much more informed than any guess and is usually based on prior experience, scientific background knowledge, preliminary observations, and logic» (Understanding Science, 2014).

		Additionally, a hypothesis is «a plausible explanation for an observed phenomenon that can predict what will happen in a given situation. A hypothesis is made based on existing theoretical understanding relevant to the situation and often also on a specific model for the system in question» (NRC, 2012, p. 67). That said, it is important to find ways to help pupils develop epistemic understanding of this concept as well as to be able to differentiate between hypotheses and predictions, since the two terms are quite often confused in textbooks and by teachers. The activities that might be used as supports for pupils in developing understanding of hypothesis as a concept and facilitate their competence in developing hypotheses in the Ark of Inquiry context are as follows: • After pupils have formulated investigative questions that are tested at a later stage through designing specific investigations, ask pupils to write in the left column of a two column table their investigative questions and prompt pupils to write next to each investigative question an *explanation* of *how* they think the relationship of the two variables of each question is. Remind pupils that they should not focus on writing what the result of the planned experiment would be (this would be a prediction) or merely answering the investigative question by stating that Variable A affects/does not affect Variable B. For instance, if the investigative question is «Does the type of surface of a ramp affect the time of the flight of a ball rolling down the ramp?», the pupils are expected to write something like «Rougher surfaces will impede the ball from rolling on the ramp and thus the time of flight will be

		greater than in the case of ramps with smooth surfaces». • If the hypothesis formulation precedes the formulation of investigative questions, then follow the same format as for the abovementioned activity, but in a reverse order. If pupils succeed in formulating hypotheses based on previous experience, scientific knowledge and preliminary observations and their hypotheses relate to proposed explanations of how a phenomenon functions, then prompt them to write next to each hypothesis an investigative question through which their hypothesis could be confirmed or rejected. • If pupils fail to formulate hypotheses that are explanation oriented statements and their hypotheses are mere guesses or predictions, we can scaffold their understanding of the nature of hypothesis by providing three statements (a hypothesis, a prediction, and a guess) in the context they are experimenting with and ask them to discuss with their peers which of the three statements provides an explanation of how and why a phenomenon functions. This activity can be repeated several times with new statements until pupils appear to distinguish between statements that are explanations (and thus they are considered as hypotheses) and statements that relate to the outcome of an experiment (and thus they are considered as predictions). The activity can be extended to new (or unfamiliar) contexts and pupils' success in differentiating between hypotheses and predictions will serve as an indicator of the development of their hypothesis formulation competence.
INVESTIGATION *The process of*	Exploration *The process of*	Given that both the Exploration and Experimentation sub-phases involve the

planning exploration or experimentation, collecting and analysing data based on the experimental design or exploration	*systematic and planned data generation on the basis of a research question.*	design and implementation of an exploration or an experiment based on the investigative question and/or the previously formulated hypothesis, the suggested supports for both sub-phases are provided interchangeably. Quite often, pupils encounter difficulties during designing an experiment to test a hypothesis or answer an investigative question because they lack the control of variables skill. This skill pertains to a learner's competence in designing a valid experiment (or a fair test) in which only one variable is altered (the independent variable, i.e. the variable the impact of which on the dependent variable is tested) and all other variables that might influence the effect of the independent variable on the dependent variable are controlled (or kept constant). Because pupils' experimental designs might include uncontrolled experiments (e.g., more than one variable is altered or not all other variables are kept constant), pupils will need substantial support at this stage. • A heuristic that will help pupils in designing a controlled experiment is as follows: ask pupils to break down their investigative question into two parts; the part before the verb «affect» should entail the variable that needs to be altered in their experiment (the independent variable), and the part that follows the verb «affect» should contain the variable that has to be measured (the dependent variable). Based on this breakdown, prompt pupils to choose which of the two variables is going to be altered and which is going to be measured in their experiment. After pupils' success in identifying both variables and how they should be treated within their experiment, prompt pupils to think of and discuss with their
	Experimentation *The process of designing and conducting an experiment in order to test a hypothesis*	

		peers how the rest of the variables that might affect the experiment should be treated in their experimental design. Provide specific examples of variables and ask pupils to state whether each of these should be altered or kept constant during their experimentation. Through this approach, the pupils should understand that in order to design a valid experiment, only one variable should be altered and all the other variables should be kept constant. • Before pupils execute their experiment, provide them with an experimental design that does not meet the requirements of a controlled experiment (e.g., tell pupils that this is an experiment designed by a group of pupils of the same age) and ask pupils to comment on whether the given experimental design refers to a controlled experiment. If pupils have already developed the control of variables skill through the previous activity, then they should be able to identify the flaws of the given experimental design and suggest improvements in order to reach a controlled experiment. This activity can be repeated with several experimental designs in other domains than the one the pupils are working in if we aim at examining the development and transfer of the control of variables skill in new domains. • Another domain in which pupils encounter difficulties during the Exploration and Experimentation phases and need support concerns the planning and execution of their experiment. This difficulty relates to the absence of the skill of planning from their skills' repertoire. «Planning is a complex skill requiring experience and ability to think through to the possible outcomes of actions» (Harlen, 2012, p.15). It is suggested that young pupils

		can be introduced to planning by posing questions to them during the planning and execution phases, such as “Tell me what you are going to do in this experiment!” or «How are you going to change the variable A in your experiment, how are you going to measure variable B in your experiment?», etc. Also, Harlen (2012) suggests that if the investigation is observational rather than experimental, it is important to prompt pupils to decide with their peers what would be important to observe during the execution of their experiment, how they will observe, and how they will collect their data. This is an important step in their planning, since pupils quite often fail to choose a functional way to measure the effect of the variable they are testing on the dependent variable. For instance, in the context of kinematics, and specifically while investigating the factors that affect the time of flight of spheres that are rolling down a ramp, the pupils quite often suggest that a timer would be the best tool to measure the time of flight. However, given the relatively small size of the ramp, the pupils will not be able to arrive at valid measurements. Hence, it is important to help them think of alternative ways for measuring the time of flight; for instance, we can prompt them to use their senses (both vision and hearing) in order to decide if two spheres rolling down the ramp reach the end of the ramp at the same time or different times. This can be achieved easily by focusing on the nature of the sound that emerges (e.g., a single sound indicates that both spheres reach the end of the ramp at the same time, whereas two distinct sounds indicate a difference in the time of flight) and on the visual outcome of the spheres when reaching the end of the ramp.

		• Another instructional technique that will support pupils' engagement with the inquiry activity during the Investigation phase is the predict-observe-explain cycle (POE) (White & Gunstone, 1992). Both the predict and observe stages of the POE cycle concern the Exploration and Experimentation sub-phases of the Investigation phase, whereas the explain stage applies to the Data Interpretation phase (see Data Interpretation sub-phase below). Prediction is an important aspect during pupils' engagement with the Investigation phase, because it increases their curiosity, motivation and anticipation of the outcomes of their designed experiment. To facilitate pupils' formulation of predictions, we can ask them to draw on prior knowledge and state what will occur during their experiment or what they might come up with at the end of their experiment. Pupils can be encouraged to make individual predictions, then share them with their peers, make arguments for their predictions and come to a consensus over what is more feasible to happen when executing their experiment. It is important to let them know that in case strong arguments occur for two competitive predictions, then both predictions can be maintained and the experimental outcome can be used as a means for testing these predictions. This is an essential step in formulating their predictions, since pupils, especially young ones, might feel uncomfortable in formulating a prediction that will be rejected at the end. Teachers' impact at this point is fundamental, since they can make pupils aware that they can pose a prediction in an attempt to model how they draw on their prior knowledge and experience to determine what might happen. This can be achieved by

		adopting the «thinking aloud» technique, through which they can coach pupils in monitoring explicitly the process of formulating a prediction. • In general, during the Exploration and Experimentation phases, we need to help pupils remain on track with their investigative question or hypothesis and scaffold their efforts in designing and applying their experiments both conceptually and procedurally. Pupils should be reminded at certain points during their investigations to revisit their hypothesis or question and verify whether the data or evidence they are collecting is adequate or relevant to their initial plans and decide when they have collected enough evidence/data for answering their questions or verify/reject their hypothesis. • Additionally, because pupils are not familiar with the materials and infrastructure that are available in the science class, it is important for teachers to anticipate what equipment and materials pupils might need while designing their investigations, show them what is available and tell them to make their selection from the equipment and materials when they have decided what to do. • Finally, given that the sub-phase that follows relates to data interpretation, it is advised to prompt pupils to organise/represent the data collected in tables, graphs, etc. in a such a way that making meaning out of the collected data is facilitated through the medium selected for their representation. Hence, we can prompt pupils to select the best representational medium that fits their data through providing examples of how the set of data can be organised. Of course, this presupposes that the pupils have an understanding of all these means of data organisation and representation. If not, this is

		another issue that the teachers need to address by introducing all these means to their pupils.
	Data interpretation *The process of making meaning out of collected data and synthesising new knowledge*	Pupils will enter the Data Interpretation phase right after they have performed their experiment through which they aimed to answer their investigative question or prove their hypothesis. When entering this phase they need to make sure that the data collected is correct (in the sense that the data concern the variables under study) and adequate for making meaning and synthesising new knowledge. Consequently, two critical questions that serve as a support at this stage could be as follows: «Did you collect the correct data that will help you in answering your investigative question or confirm/reject your initial hypothesis?» and «Did you collect enough data that will help you in answering your investigative question or confirm/reject your initial hypothesis?» If either or both questions are negative, then pupils should be encouraged to repeat their experiment until they are satisfied with the set of the collected data. If pupils are ready to proceed in interpreting their data, then the following prompts can act as supports for their interpretations: • *«What claims or propositions can you make that are supported by the evidence gathered?* • *What tentative explanations might they come to?* • *How do these compare with their starting assumptions and predictions?»* (Harlen, 2012, p.15) In addition, during data interpretation pupils should be prompted to compare their predictions to the data collected and develop explanations about inconsistencies. This step will help pupils to better monitor the development of their understanding of

		the phenomenon under study, since through revisiting their predictions they are given an opportunity to access their original ideas and check whether these have been confirmed or not during their experimentation. Here again teachers can model how the generation of explanations is processed and consider whether the explanation is adequate, coach pupils as they develop explanations, and underline the necessity of taking into consideration various key features that derive from their data. Another anticipated outcome of the Data Interpretation phase concerns pupils' ability to define the type of relation between the tested variables. In order to achieve this learning goal, pupils should be able to draw inferences from the collected data about how the independent variable affects the dependent variable. The nature of the relation between the two variables is constrained by the type of variables that have been tested. The most common types of variables that pupils will encounter during their investigations are the *categorical* (sometimes called nominal), the *ordinal*, and the *interval*. A *categorical* variable is one that has two or more distinct categories, but there is no intrinsic ordering in the categories. For instance, colour, gender, type of plants, etc. are categorical variables, because each of them has a certain number of categories that cannot be ordered. An *ordinal* variable is similar to the categorical variable, but its categories can be clearly ordered. For instance, the ranking of objects according to their volume (e.g., small, medium, big) or the ranking of surfaces according to their transparency (e.g., transparent, semi-transparent, non-transparent) are ordinal variables, because their values can be

		ordered according to a specific criterion. Lastly, an *interval* variable is similar to the ordinal variable, but the intervals between the values of the interval variable are equally spaced (e.g., time, temperature, mass are examples of interval variables). Consequently, it is important to make sure that pupils can distinguish between the three types of variables as well as define the type of relation that appears to exist based on the evidence collected from their experiments. For instance, if both variables are ordinal or interval, the pupils should be scaffolded to define the relation as follows: "the more variable A increases or decreases, the more variable B increases or decreases". If both variables are categorical (sometimes called nominal), then the type of relationship that is expected to be extracted should be a description of how specific values of variable A appeared to affect the values of variable B. To help pupils formulate a comprehensive relation between the variables, prompt them to describe first the data collected for both variables that have been tested and then pose questions like «What happened to the value of variable B when variable A was increasing or increasing?», «How can we make a statement that will indicate the direction of the relationship between variable A and variable B?»
CONCLUSION *The process of drawing conclusions from the data. Comparing inferences made based on data with hypotheses or research questions*		Pupils should proceed to the Conclusion phase after significant time was invested in the preceding phase during which pupils made interpretations on the basis of the data collected during their experiments. Both the Data Interpretation and the Conclusion phases are closely aligned, because pupils are expected to draw conclusions based on their interpretations. The Conclusion phase is also linked to the Conceptualisation phase, as pupils should

		be able to compare inferences that departed from their data with their initial hypotheses or research questions. In doing this, pupils will need support and feedback on the conclusions they will be formulating, because this is not a straightforward procedure that they can follow on their own. To facilitate their work, we can ask them to revisit their investigative question and/or hypothesis and decide if their interpretations are aligned with their original questions or hypotheses. In case their original hypotheses are not supported, they should be prompted to develop new hypotheses that would be consistent with the interpretation of the data that was undertaken during the previous phase. Again, questions like «What claims or propositions can you make that are supported by the evidence gathered?» or «What tentative explanations might they come to?» will help pupils formulate new hypotheses through which the relation between the tested variables can be explained. In case the data do not designate a relationship between the tested variables, the pupils should be prompted to identify new variables whose effect would be tested and thus a new round of investigation can be initiated. If pupils encounter difficulties in identifying new variables, a heuristic that can be used to facilitate their work is to ask them to revisit the Conceptualisation phase and check if during that phase they have identified more than one variable the effect of which on the dependent variable they would like to test. In formulating their conclusions it may be useful to help pupils distinguish between claims supported by the evidence they collected (e.g., "The time of flight of a ball rolling down a ramp with a rough surface is greater compared to the time of flight of the same ball rolling down an identical ramp with a smooth surface.") and explanations which are attempts to explain

		why or generalise from the specific claims (e.g., "I think this is because the friction force that is exerted on the ball at the rough surface is greater than the friction force exerted on the ball at the smooth surface.").
Discussion		Discussion transcends all the previous inquiry phases and sub-phases. It is an essential ingredient for promoting collaboration through the exchange of ideas at any point of the inquiry process. If needed, teachers should constantly remind their pupils of the value of mutually exchanging ideas and critiquing each other's work. Peer feedback has been shown to be a valuable learning asset for both peer assessors and peer assessees (Hovardas et al., 2014).