Ark of Inquiry: Inquiry Activities for Youth over Europe

Deliverable D2.1

Criteria for selection of inquiry activities including societal and gender dimensions

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Summary

The Ark of Inquiry project aims to build a scientifically literate and responsible society through Inquiry-Based Science Education. The project seeks to expand young people's awareness of Responsible Research and Innovation (RRI) by disseminating across Europe engaging inquiry activities in STEM domains.

The current deliverable provides selection criteria for existing inquiry activities to be included in the Ark of Inquiry project that will be available for students (and teachers) across Europe through the Ark of Inquiry Portal. The criteria are based on a theoretical rationale and contemporary research evidence and support the selection of successful inquiry activities. The aim of the criteria is to ensure that as a whole the selected activities will promote inquiry learning (and curricula) in STEM domains, be productive and engaging for students at various age and skill levels, be gender inclusive, and promote students' awareness of societal responsibility.

The proposed selection criteria consist of seven mandatory and two recommended elements. The mandatory criteria are considered core characteristics/elements that need to be fulfilled by each inquiry activity, in order to be included and distributed through Ark of Inquiry. The recommended criteria are considered important because they are believed to contribute to fulfilling both the specific and higher order goals of the project; however, because of the focus on existing activities (not designed with these criteria in mind) it cannot be expected that all activities fulfil them.

Although the main focus of the deliverable is on the selection criteria, the deliverable also provides criteria for describing the inquiry activities, as the descriptions of inquiry activities and the selection criteria for the inquiry activities are closely interlinked. One can see the descriptions as means to transfer the actual selection criteria into a format that is visible and understandable to the users of Ark (i.e. students, teachers, and parents) and that will help them to find and select activities that are (the most) suitable and engaging in a given context.

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1. Introduction

The Ark of Inquiry project aims to build a scientifically literate and responsible society through inquiry-based science education. The project seeks to expand young people's awareness of Responsible Research and Innovation (RRI) by disseminating across Europe engaging inquiry activities in STEM domains.

The current deliverable, which builds on Deliverable 1.1.of Work Package 1, provides selection criteria for existing inquiry activities to be included in the Ark of Inquiry project and distributed for students (and teachers) across Europe through the Ark of Inquiry Portal. The aim of the criteria is to ensure that as a whole the selected activities will, in accordance with the project work plan:

1. promote inquiry learning (and curricula) in STEM domains;
2. be productive and engaging for students at various age and skill levels;
3. be gender inclusive;
4. promote students' awareness of societal responsibility.

Although the main focus of the deliverable is on the selection criteria, the deliverable will also provide criteria for describing the inquiry activities. The descriptions of inquiry activities and the selection criteria for the inquiry activities are closely interlinked, because the descriptions are means to transfer the actual selection criteria into a format that is visible and understandable to the end users. The descriptions become relevant once the selected inquiry activities are published in the Ark of Inquiry Portal, because they display a summary of each activity and provide a search filter that will help the users of Ark (i.e. students, teachers, and parents) to find and select activities that are (the most) suitable and engaging in a given context.

The main content of this deliverable is divided into five sections. The first section provides a rationale for inquiry learning and outlines its key characteristics. The second section discusses ways to implement inquiry learning in a productive and engaging manner. These two sections create a basis for the third section, the most important part and outcome of this deliverable, presenting the actual selection criteria for the inquiry activities within the project. The fourth section outlines a set of criteria for describing the inquiry activities (that pass the selection criteria) for the Ark of Inquiry Portal. In the fifth section an inquiry activity example is reviewed against the selection criteria with the aim to clarify and concretise the selection criteria and help the project partners (and other contributors listed in the DoW) to evaluate their existing inquiry activities against the criteria.

2. Foundation for the selection criteria

2.1. Definition of and rationale for inquiry learning

Traditionally instruction typically used to be teacher-centred. The emphasis was on learning (or memorising) factual knowledge (typically from textbooks and hand-outs) and students had only limited opportunities to test their own ideas and conceptions. This is in conflict with the contemporary research evidence and theories of learning, which show that students learn better when they have an active role in the learning process and their understanding of scientific principles is formulated within the framework of their prior knowledge (Bransford, Brown, & Cocking, 2000). Furthermore, according to the "Rocard report" (Rocard et al., 2007), the origins of the alarming decline in students' interest for STEM domains can be found in the old-fashioned way these topics are typically taught at schools.

Inquiry learning is student-centred. In inquiry learning the students are engaged in an active exploration process[1]; the answers are not directly visible to them; instead, they are invited (and typically also guided) to conduct their own investigations in the subject matter and gradually induce (de Jong, 2006) or deduce (Chen, 2010) the answers and underlying principles of the domain from these investigations. While conducting the investigations, the students are able to test their own conceptions and compare these with the results of the investigations (de Jong, 2006; Wieman, Adams, & Perkins, 2008): it is well established that in order to promote deep conceptual understanding in STEM domains, it is equally important to activate students' prior conceptions as it is to provide them with accurate information, because misconceptions that are an integral part of initial conceptions can prevent learning accurate information (M. Chi, 2008; Vosniadou, 2002). Apart from seeking to improve students' understanding of the topic of the investigation, a higher order goal of inquiry learning is that while conducting the investigations, the students also improve their skills and awareness of conducting (scientific) inquiry.

In the work plan of Ark of Inquiry (i.e. DoW), inquiry learning is defined according to the definition of the US National Science Foundation (2000, p. 2) as *"an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science".*

[1]Critical note: when designing inquiry-based instruction, behavioural activity should be considered as a means to promote kind of cognitive activity that promotes learning, not as an end in itself (Mayer, 2004). In other words, the behavioural activity per se does not guarantee desired learning outcomes.

As specified in the DoW, the project aims to collect successful inquiry learning activities based on a concrete set of quality criteria. In the next section, the notion of successful inquiry activities will be elaborated upon, and after that, criteria to select successful activities will be derived from there.

2.2. Successful inquiry

Within the context of Ark of Inquiry, successful inquiry activities will be defined along the learning outcomes and the engagement dimension of the inquiry. In both dimensions, domain and inquiry can be distinguished. An inquiry activity can be called successful in relation to learning outcomes if through this particular inquiry activity, students learn about the domain. Likewise, it can be called successful with respect to inquiry if students learn about inquiry itself, but of course in the ideal case students learn about both. In the engagement dimension inquiry activities can be called successful if the activity engages the students in the domain, as this will, apart from its potentially positive effect on the learning outcomes, likely raise their interest in the scientific domain. Successful engagement in the activity will likely raise their interest in and awareness of the process of science.

2.2.1. Productive inquiry

Inquiry learning is typically more productive in terms of learning outcomes in STEM domains than traditional instruction (see Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Minner, Levy, & Century, 2010, for reviews). However, it is critical to understand that most of the novice learners or those who do not have much prior experiences with inquiry are incapable of unguided inquiry learning. In unguided (or open) inquiry, the students are typically assigned to investigate a (given) problem space and expected to discover independently the underlying principles from these investigations. However, research over several decades has shown that unguided inquiry is often too demanding and hence unproductive, because the students are unable to plan meaningful investigations and interpret and reflect the findings of the investigations without explicit guidance and scaffolding (de Jong, 2006; Mayer, 2004). Consequently, in most cases a certain amount of instructional guidance and scaffolding is needed in order to achieve the desired inquiry outcomes. The agent providing the support and guidance can be, among others, a teacher, a worksheet, or technology. The guidance can be implemented either by structuring the domain [e.g. model progression (White & Frederiksen, 1990), or limiting the amount of variables that can be manipulated (Adams et al., 2008)], leaving more freedom in the process of exploring the domain through inquiry, or by structuring the process [e.g. VOTAT, varying one thing at a time (Tschirgi, 1980)] and leaving more freedom for choosing the domain to explore through inquiry.

Though structuring the activities along the above means guides the inquiry activity, a basic prerequisite for guided inquiry seems to be that the students have already some idea and prior experience of the processes of inquiry. If the students are complete novices and unfamiliar with inquiry learning, it may be necessary to structure both the domain and the process [e.g. Jaakkola, Nurmi, &Veermans (2011); see also the activity example in Chapter 5], otherwise the process as a whole might be overwhelming, and the purpose of the activity might get lost in floundering behaviour that neither reaches the goal of learning nor the goal of engaging the students in productive inquiry.

For the above reason many studies also use some kind of model of inquiry that pre- or describes the kind of processes involved in inquiry in more or less detail in order to provide structure and support for students, but also to introduce students to a model of inquiry that can be transferred to a different situation. Pedaste and his colleagues (submitted), for instance, who reviewed a wide range of academic papers on the process of inquiry learning and the concepts that were used to describe the process, have proposed that inquiry learning comprises the following five major phases.

1. In the *orientation phase* curiosity about a topic is stimulated, which should then result in a problem statement.
2. In the *conceptualisation phase* research questions and/or hypotheses are stated.
3. The *investigation phase* is a process of gathering and processing empirical data to resolve the research question or hypotheses.
4. In the *conclusion phase* research findings from the inquiry are reported and justified by the results of the investigation.
5. The *discussion phase* consists of communicating partial or completed outcomes of the inquiry, as well as reflective processes to regulate the learning process. This phase is unique because of its constant connection to all the other inquiry phases. It is also particularly important because it teaches students the discursive nature of science.

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

Work Package 1 (Deliverable 1.1.) has developed an Inquiry Proficiency Framework that distinguishes three inquiry levels according to how much they challenge a learner to exhibit inquiry-based behaviour and how much they require learner autonomy or how much instructional guidance and support is provided to students. Generally, the *basic level*, which is the lowest of the inquiry levels, is aimed at teaching learners how to engage in and conduct inquiry. The students are introduced to a problem within a well-defined problem space. Inquiry activities have a predefined outcome known to the teacher and/or prescribed by the learning materials. On a basic level, students learn to report and present their findings according to a worksheet or fixed presentation format to teachers and/or peers. At the *Advanced level* the inquiry activities take place in a semi-structured problem space that sets limits to the research. The main goal is to teach learners what to investigate and guide them towards independency related to knowing how to inquire. Findings are communicated in semi-structured or self-chosen formats to teachers and/or peers. At the *Expert level* students develop a research activity in an ill-defined problem space or complex societal context. They learn when to inquire and how to reflect, as well as discuss outcomes in collaboration with diverse stakeholders. For an individual student, traversing through levels of inquiry entails development into becoming an informed citizen that can take part in constructive discussions about RRI.

2.2.2. Engaging inquiry

In the previous section it was discussed how the Framework for Inquiry Proficiency can support productive inquiry by mapping activities and/or students' proficiency levels onto the phases of inquiry and the amount of support for the inquiry process that is provided in the activity. However, this alone does not yet ensure that the process is also motivating, meaningful and engaging which can be considered crucial for the goal of increasing students' interest in STEM domains.

Earlier it was already mentioned that the Rocard report (Rocard et al., 2007) identified the old-fashioned way that STEM is usually taught in schools as one of the reasons for the decline in students' interest in these domains. While in inquiry learning the focus shifts from teacher to learner, thus departing from the old-fashioned way of teaching those topics, it does not change the topics or the context in which they are taught. The ROSE (The Relevance of Science Education) project report (Sjøberg & Schreiner, 2010) identified the learning context as another reason of concern in relation to students' interest in STEM domains. In their research it was found that students are generally not very interested in science that is taught in a school context, without obvious linkage to life outside the school.

This finding held for both boys and girls, though it was even more pronounced for girls. Meaningful context also seems to mean slightly different things for each gender as boys (e.g. technical, electrical) and girls (e.g. medical, ethical) generally value different things. Generally, girls expressed more interest in working with and helping people and felt that school science is not raising enough awareness of new and exciting jobs. Adding contexts that connect content to jobs that are connecting to the general preferences of girls (e.g. connect contexts to jobs working with and helping people) might be a way to address their preferences better, while it is a means of promoting Responsible Research and Innovation at the same time. Girls were also found to believe that each individual makes a difference by giving room for contexts that connect to lifestyle choices that affect individual and societal wellbeing.

This is why the *orientation* and *discussion* phase by Pedaste et al. are particularly important. The orientation phase plays an important role for adding context: adding a meaningful orientation phase to the inquiry activity can provide the students with a context that gives relevance to the activity while at the same time activating prior knowledge that helps the inquiry process itself. The importance of the discussion phase is that it can make students understand that communicating what they have done, how they have done it and how they interpret its meaning to others is not a final product but an object of discourse calling for argumentation and allowing reflection and meaning making. This helps to convey the message that nowadays science is inherently a social act that is about collaboration and discourse and not about "alchemists looking for a way to produce gold in solitary", or about scientists sitting in their rooms waiting for a 'eureka' moment. Based on their findings, one of the implications put forward by the ROSE project researchers was "that students' own attitudes, values and interests should be given high priority in the selection and presentation of the science curriculum contents" (Sjøberg & Schreiner, 2010, p. 29). The general aim and idea of Ark of Inquiry and the way it is conceptualised in the DoW, D1.1, and this deliverable, is trying to do just that. By providing a multitude of inquiry activities within the Framework for Inquiry Proficiency, students have the opportunity to find activities that match both their skill levels and interests, and as such it likely 1) increases the productivity of the inquiry activity, 2) makes inquiry in STEM domains more attractive for both genders, and 3) promotes awareness of Responsible Research and Innovation in students.

3. Selection criteria for inquiry activities

The aim of the selection criteria that are presented in this section is to ensure that the inquiry activities that are made available for students across Europe within the project will

1. promote inquiry learning (and curricula) in STEM domains;
2. be productive and engaging for students to study on science at various age and skill levels;
3. be gender inclusive;
4. promote students' awareness of societal responsibility;

and by doing so, the criteria will help the project to reach its goal to expand young people’s awareness of Responsible Research and Innovation by disseminating across Europe engaging inquiry activities in STEM domains.

The criteria have their roots in the DoW of the project, the Framework for Inquiry Proficiency of D1.1., the inquiry phases of Pedaste et al. (submitted), and the above discussion on what can be conceived as successful inquiry activities. Both evidence-based (empirical research) and theoretical (pedagogical design) considerations should be taken into account in the evaluation of activities. It should be noted that though some of the criteria are only recommended, the entire collection of activities should be representative, that is, covering all ranges for the mandatory and recommended criteria (e.g., not only 7–10-year-olds, but the whole range of students from 7- to 18-year-olds, various STEM domains, and all proficiency levels and inquiry phases).

3.1. Mandatory criteria

The mandatory criteria (M) consist of seven core characteristics/elements that need to be fulfilled by each inquiry activity, in order to be included and distributed in Ark of Inquiry. The first four criteria derive directly from the plan as it was described in the DoW.

M1: Activity needs to be already existing

In the DoW it is emphasised that the project will collect existing inquiry activities.

M2: Activity needs to be targeted between age levels 7 to 18

In the DoW the targeted age group is from 7- to 18-year-old students across Europe.

M3: Activity needs to be in a STEM domain

In the DoW it is stated that the project has its focus on STEM domains. STEM encompasses the domains of science (physics, chemistry, and biology), technology, engineering and mathematics.

M4: Activity needs to support inquiry learning

The activity needs to support inquiry learning. The former chapter provides a definition of inquiry learning as originally presented in the DoW of the project. Generally speaking, the key characteristics of inquiry learning are that the activity is student-centred, the students are engaged in an active exploration process (the degree of freedom in the exploration process depends on the targeted proficiency level); the answers are not directly visible to them; instead, they are invited and typically also guided (the amount of guidance will depend on the targeted proficiency level) to conduct their own investigations in the subject matter and gradually induce or deduce the answers and underlying principles of the domain from these investigations.

M5: Activity needs to cover at least one inquiry phase

The activity needs to cover, at the minimum, one of the (below) five inquiry phases of Pedaste et al. (submitted). This superficially loose criterion stems from the fact that the existing inquiry activities where not designed these particular phases in mind, and that even an activity that covers only one inquiry phase may cover/address that phase particularly well. However, activities covering multiple phases are highly recommended and desired, because in the absence of empirical evidence, a pedagogically informed design covering the phases of inquiry will also be more likely to achieve the goals of the Ark[2] (see also M7).

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[2]Ideally an activity would cover all the five main inquiry phases proposed by Pedaste et al. (submitted) as this enhances the likelihood of obtaining positive outcomes for learning and engagement on both domain and inquiry. This implies that all phases are identifiable within the activity and that it should in

1. In the *orientation phase* curiosity about a topic is stimulated, a problem space that is more or less defined is explored in guided or self-initiated ways, which should then result in a problem statement. The orientation phase places the inquiry activity in a wider context. It has an important role for providing personal meaning to the activity, and subsequently for fostering engagement, societal responsibility and gender inclusiveness.
2. In the *conceptualisation phase* research questions and/or hypotheses are stated. In this phase the problem space for the inquiry activity is further defined: through research questions (and hypotheses), the scope and boundary of the inquiry activity are set.
3. In the *investigation phase* students process[3] empirical data either gathered by themselves or by others to resolve the research question or hypotheses. Within the boundaries defined in the conceptualisation phase, empirical data related to variables needs to be processed with the purpose of answering the research questions and/or hypotheses.
4. In the *conclusion phase* the main research findings and implications from the inquiry are formulated, justified and discussed by synthesising the results of the investigation.
5. The *discussion phase* consists of communicating outcomes of the inquiry, as well as reflective thinking on the outcomes and the inquiry (learning) process. This phase is unique because of its constant connection to all the other inquiry phases. As such it might function as the catalyst for the cyclic nature of inquiry. In any phase discussion can trigger a reconceptualization of the activity in that phase, or trigger a reconceptualization of the activity in one of the earlier phases. Therefore it is important to see if this connection is established to all phases, and if it is not how it could be added.

M6: Activity needs to map on a specific inquiry proficiency level

The activity needs to map on one of the inquiry proficiency levels (Basic, Advanced or Expert) specified in D1.1. and described in chapter 2.2. of this document. Though the expectations are that only few activities map consistently on (just) one proficiency level, it is important that the activity as a whole is mapping on one level, thus excluding unbalanced activities (e.g. combining an ill-defined problem with pre-specified conclusion template, or constrained problem with unguided inquiry). The main distinctive features between the inquiry proficiency levels are problem-solving type (well- vs ill-defined problem space), learner autonomy (from teacher-led to student-led), and RRI awareness (gradually expanding the amount and scope of interaction/discussion).

On the lowest inquiry proficiency level (entitled Basic level), the students require a lot of support and guidance for the inquiry activity in order to succeed; *it is typically necessary to structure both the domain and the inquiry process*. More specifically, the

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principle be possible to map their manifestation on one of the inquiry proficiency levels. (Chapter 5 below will provide an example of how this works).

[3]We prefer to use the word "processing" instead of "gathering", because it refers to cognitive activity, whereas gathering refers to a behavioural activity. In addition, it does not take a position on whether the data that is processed during the investigation phase is actually gathered or provided.

students are introduced to a problem within a well-defined problem space; inquiry activities have a predefined outcome known to the teacher and/or prescribed by the learning materials. Inquiry at the basic level is aimed at teaching learners how to engage in and conduct inquiry in order to develop into informed citizens. Students learn to report and present their findings according to a worksheet or fixed presentation format to teachers and/or peers.

On the next proficiency level (Advanced level) inquiry activities take place in a semi-structured problem space that sets limits to the research but also leaves space to choose or define a specific topic or subdomain. A certain amount of instructional guidance and scaffolding is still necessary in order to achieve the desired inquiry outcomes. The guidance can be implemented either *by structuring the domain* (or limiting the amount of variables that can be manipulated, Adams et al., 2008; e.g. model progression, White & Frederiksen, 1990), or *by structuring the process* (e.g. VOTAT, varying one thing at a time, Tschirgi, 1980). The main goal is to teach learners what to investigate and guide them towards independency related to knowing how to inquire. Findings are communicated in semi-structured or self-chosen formats to teachers and/or peers, preparing them to be informed citizens.

On the highest level (Expert level), inquiry activity is *unguided or minimally guided* (i.e. open inquiry) and the students are expected to take the initiative and more responsibility for the whole inquiry process. They develop a research activity in an ill-defined problem space or complex societal context. They learn when to inquire and how to reflect, as well as discuss outcomes in collaboration with diverse stakeholders, turning themselves into informed citizens that can take part in constructive discussions about RRI.

As mentioned above, some parts of the activity can deviate from the target level (e.g., the investigation phase may be more or less demanding compared to the other phases). Chapter 4 below provides a tool to communicate such departure to users.

M7: There needs to be evidence on the success of the activity

There needs to be evidence on the effectiveness of the inquiry activity in terms of learning outcomes, engagement, or both. Ideally an inquiry activity would be successful in terms of both learning outcomes and engagement on both domain and inquiry, but even if there is evidence for only one of the indicators, this already increases the likelihood that the activity will also be successful within Ark of Inquiry.

The following four types of evidence are identified, and an activity needs to be supported by at least one of them.

1. *Direct empirical evidence* refers to research evidence that has been obtained from the implementation/use of the particular activity.

2. *Indirect empirical evidence* refers to a situation where an original activity that is supported by direct empirical evidence has been modified/adapted, and there is no direct empirical evidence on the effectiveness of the modified activity.
3. *Theoretical evidence* refers to theoretically informed design principles that have been applied in the design of the activity (e.g. covering and/or supporting all inquiry phases).
4. *Ecological evidence* refers to evidence that has been obtained from daily (school) practices. As an example, an activity that has been used widely in a specific country/region/community, and/or that has received an official recognition or prize can be considered to be supported by ecological evidence.

3.2. Recommended criteria

Recommended criteria consist of elements that should be included in the activity whenever possible, because these elements are believed to contribute to fulfilling both the specific and higher order goals of the project. However, because of the focus on existing activities that were not designed with these criteria in mind it cannot be expected that the activities fulfil all of them.

R1: Support for societal responsibility and gender inclusion

In section 2.2.2.on engagement, the orientation and discussion phases where identified as phases that could be the most appropriate for implementing dimensions of responsible inquiry and gender inclusiveness into the inquiry activities. Therefore, it is recommended to devote specific attention to reviewing how these dimensions are addressed in the activity. This entails identifying how and what kind of context is provided in the orientation phase. Kinds of contexts that might engage more girls in the inquiry activity are presumably real-life problems and contextually rich problems. Furthermore, it entails identifying how the discussion phase connects the context to the inquiry process and how frequently and how it supports reflection and communication with an audience. Inquiry activities that foresee several moments of presentation and discussion with peers, experts and/or stakeholders (wide audience) during more than one inquiry phase probably provoke RRI more than inquiry activities that only report findings to the learner and teacher (small audience).

R2: Integration between learning content and inquiry skills

Although in principle, one could argue that all inquiry activities should establish a connection between the content and inquiry process, it is not always so that both aspects develop when students work on an activity. Scientists can work on a scientific problem according to well established methods, thus developing scientific knowledge, in a known domain (that serves as a benchmark) on developing new scientific methods, or, as most often is the case, do both at the same time. In principle, the same holds for students, but while scientists working with established methods or on known domains can be assumed to be well aware of the reasons for doing this, it is not obvious for students. For instance, when students work on a structured inquiry activity targeting at certain domain knowledge, they might not realise the underlying idea of the inquiry unless the link between the inquiry process and knowledge that is derived through the activity is explicitly addressed. The same holds for an activity that focuses on developing inquiry skills (e.g., Control Variable Strategy). Without connecting CVS to making meaningful inferences, it would likely fail to develop an understanding of the role that controlling variables plays in science. One of the aims in the Ark project is that individual students develop from the basic to the expert inquiry level, which entails learning about the domains of inquiry as well as learning inquiry skills, and as such, students should be or become aware of why they are doing what they are doing when engaged in an inquiry activity. It is therefore recommended that activities in the Ark explicitly integrate both content and inquiry aspects of the activity by providing context to the role of inquiry processes in the development of scientific knowledge in primarily content related inquiry activities and context meaning of inquiry processes for scientific knowledge development in primarily inquiry related activities.

4. Criteria for describing inquiry activities

In Ark of Inquiry the inquiry activities that pass the selection criteria will be made available for students through the Ark of Inquiry Portal. In order to make sure that the students find the kind of inquiry activities from the portal they are looking for and that are (the most) suitable for them, it is important that each activity has an appropriate description and keywords. This section will list mandatory and recommended elements of descriptions. Mandatory elements contain information that is necessary to enable the retrieval of inquiry activities. They must be filled in for every inquiry activity. Recommended elements are elements that should be filled in whenever possible to maximise the search criteria and make sure that the students find appropriate materials as easily as possible.

The elements, excluding those marked with an asterisk (*), are based on the "Learning Resource Exchange Metadata Application Profile version 4.7" of the European Schoolnet (Massard & Shulman, 2011), which is based on the IEEE LOM (LOM stands for Learning Object Metadata) standard with an early version of the IMS LODE Information for Learning Object Exchange (ILOX) specification, a framework for organising existing standards such as LOM. Adaptation of this standards-based framework will improve the sustainability of Ark of Inquiry, as the standards enable technical interoperability of activities between the Ark of Inquiry Portal and other portals that contain inquiry activities or other types of learning resources.

4.1. Mandatory elements

- LANGUAGE: (the language(s) of the activity; e.g., English, Finnish)
- DOMAIN: [the domain of the activity; science (physics, chemistry, biology), technology, engineering and mathematics]
- DESCRIPTION OF THE ACTIVITY: (as detailed overall description of the activity as possible; the description should help users to select appropriate activities and use them)
- INQUIRY PROFICIENCY LEVEL: (Basic, Advanced, or Expert)*
- COVERED INQUIRY PHASES: (orientation, conceptualisation, investigation, conclusion, discussion)*
- INQUIRY PHASES DEPARTING FROM THE PROFICIENCY LEVEL: (none, orientation, conceptualisation, investigation, conclusion, discussion)*
- MATERIALS NEEDED FOR THE ACTIVITY: [each activity needs to specify all the materials that are needed for the activity. Such materials can be virtual (e.g., a computer-based simulation) and physical (e.g., real equipment, computer, worksheet)*.
- EVIDENCE ON THE SUCCESS OF THE ACTIVITY: (Direct empirical evidence, Indirect empirical evidence, Theoretical evidence, and/or Ecological evidence)*

  - EVIDENCE DESCRIPTION: (Evidence on the success of the activity should be described here)
- COPYRIGHT AND OTHER RESTRICTIONS: (yes, no)
  - RIGHTS DESCRIPTION: (if the answer to above was yes, then the restrictions should be specified in this section)

4.2. Recommended elements

- TITLE: (Descriptive title of the activity)
- KEYWORD(S): (free keywords that capture the essence of the activity)
- TOPIC: (The specific topic of the activity, e.g., electric circuits. This extends the domain attribute from the mandatory elements)
- TYPICAL AGE RANGE: (somewhere between 7 and 18 years old, as specified in the DoW; e.g., 7–10)
- TYPICAL LEARNING TIME: (minutes)
- SUPPORT FOR SOCIETAL RESPONSIBILITY AND GENDER INCLUSION: (Description of how the activity specifically addresses RRI elements)*
- TARGETED LEARNING OUTCOME: (Domain content, Inquiry skills, Domain content and inquiry skills)*

5. An inquiry activity example reviewed against the selection criteria

In this section an example of an existing inquiry activity is reviewed against the selection criteria by describing it according to the above-listed mandatory and recommended elements for describing inquiry activities. The aim is to clarify and concretise the above selection and description criteria and help the project partners (and other content contributors listed in the DoW) to evaluate their existing inquiry activities against the criteria. In the following section, the capital letter *M* stands for mandatory element and R for recommended element in the selection criteria. Small *m* and *r* stand for mandatory and recommended activity descriptors, respectively. Elements that are directly related to the selection criteria are further highlighted with a bold font.

- Title (r): Exploration of basic principles of electric circuits
- **Domain (M3, m): Physics, Electricity**
- Topic (r): Simple DC circuits
- Language (m): Finnish, English
- **Inquiry Proficiency Level (M6, m): Basic**
- **Covered Inquiry Phases (M5, m)**: conceptualisation, investigation, conclusion
- Inquiry Phases Departing from the Proficiency Level (m): None
- **Typical Age Range (M2, r): 11-13**
- Typical Learning Time (r): 90 minutes
- Materials Needed for the Activity (m): Computers with an Internet connection and Internet browser that has an Adobe Flash Plug-in (note: the simulation associated with the activity can be replaced with another simulation or real equipment), printed worksheets and pencil
- **Evidence on the success of the activity (M7, m): Direct empirical evidence, Theoretical evidence**
  - Evidence description (m): The effectiveness of this activity, both in terms of learning of *outcomes* and *engagement*, has been verified by several scientific studies (**direct empirical evidence**). It has been found that this activity helps students to learn the basic principles of electric circuits and overcome many of their misconceptions (Jaakkola, Nurmi, & Lehtinen, 2010). An average effect size that indicates the "amount" of learning has been around one standard deviation unit, which is generally considered as a large learning effect (Jaakkola & Veermans, submitted). Although this activity can be completed by using real equipment, the use of a computer simulation (or a combination of real equipment and a simulation) is recommended, because the use of the simulation is likely to result in better understanding of the circuits than the use of real equipment alone (Jaakkola & Nurmi, 2008). The activity has also been rated as highly engaging by both girls and boys (Tapola, Veermans, & Niemivirta, 2013) **(R1)**. The success of this activity is also supported by **theoretical evidence**: The worksheets that guide and scaffold students' inquiry process are designed to confront common misconceptions of electric circuits, which have been

identified by a large body of previous studies, (e.g. McDermott & Shaffer, 1992; Reiner, Slotta, Chi, &Resnick, 2000; Targiso Borges, 1999) and to correct these misconceptions by gradually introducing the scientific model.

- Copyright and other restrictions (m): Yes
  - Rights description (m). The simulation (The Electricity Exploration Tool) that is part of the activity is courtesy of Digital Brain PLC and is copyrighted. Worksheets associated with this activity belong to a public domain, i.e. they are free to use in any context.
- Keywords (r): Physics, Electricity, DC circuits, series circuits, parallel circuits, voltage, brightness, Elementary school
- Description of the Activity (m): In this activity students are guided to explore the basic principles of electric circuits by using a computer-based simulation that models the functioning of electric circuits **(M4)**. The objective of the activity is to discover the basic principles behind the functioning of the electric circuits on a qualitative (relationship between the number of bulbs, the circuit configuration, and the bulb brightness) and quantitative (relationship between the number of circuit components, the circuit configuration, and the voltage across circuit components) level[4]. The activity consists of a series of 9 worksheets that are designed to activate students' prior conceptions on electricity, confront common misconceptions identified by previous research, (e.g., McDermott & Shaffer, 1992; Reiner et al., 2000; Targiso Borges, 1999) and to correct these misconceptions by gradually introducing the scientific model (see appendix for three exemplary worksheets). The worksheets instruct students to construct various circuits and conduct various electrical measurements with a simulation that models the functioning of electric circuits (see below for more details on the simulation). The worksheets also contain instructional scaffolds that ask the students to investigate and infer how the changes and differences in circuit configurations affected circuit behaviour **(M7, m)**. The circuits and circuitry in the worksheets are presented as a realistic picture and as a simulation view. Each worksheet focuses on one topic and gradually become more difficult. Each worksheet provides the students with pre-structured conclusion statements. It is recommended that the students receive one worksheet at a time, and that they receive the next worksheet only after they have completed the previous worksheet correctly (i.e. correct conclusions). The role of the teacher (or parent) is to monitor students' progression and check their answers after the completion of each worksheet. It is further recommended that the students should work in pairs. The activity is not recommended for students under 11 years of age, because it has been found that 10-year-old students do no gain nearly as much from the activity as older students (Jaakkola & Veermans, submitted).
- The activity covers three of the five inquiry phases: conceptualisation, investigation, conclusion (see appendix for more details on the implementation of the phases). In the original context the activity covered four phases together with an orientation phase

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[4]In order to develop a proper understanding of electric circuits in students, many researchers have suggested that students should first adopt qualitative and a voltage-centred view of electric circuits (e.g. Cohen, Eylon, & Ganiel, 1983; Lee & Law, 2001; White & Frederiksen, 1990). A proper understanding of the concept of potential difference (voltage) is very important in understanding electric circuits, because the qualitative rules that govern the voltage redistribution process are related to well-known laws of quantitative circuit theory, namely Kirchhoff's Voltage Law and Ohm's Law (Reiner et al., 2000; White & Frederiksen, 1990).

that included a general introduction to the topic, worksheets, and the simulation; it was in oral format and there is no reason why this could not be provided by a teacher. What should be noted is that, even though it could qualify as orientation, it would not qualify as orientation that provided a meaningful context to the students in a way that could be expected to raise their awareness of RRI. Other than that, the students are working in pairs (and are expected to communicate with each other), discussion is not addressed in the activity. An orientation phase providing more meaningful context, and a discussion phase connecting the conclusions to the meaningful context could be considered improvements of the activity.

- The simulation that is associated with the activity is called the 'Electricity Exploration Tool' (EET, Figure 1).

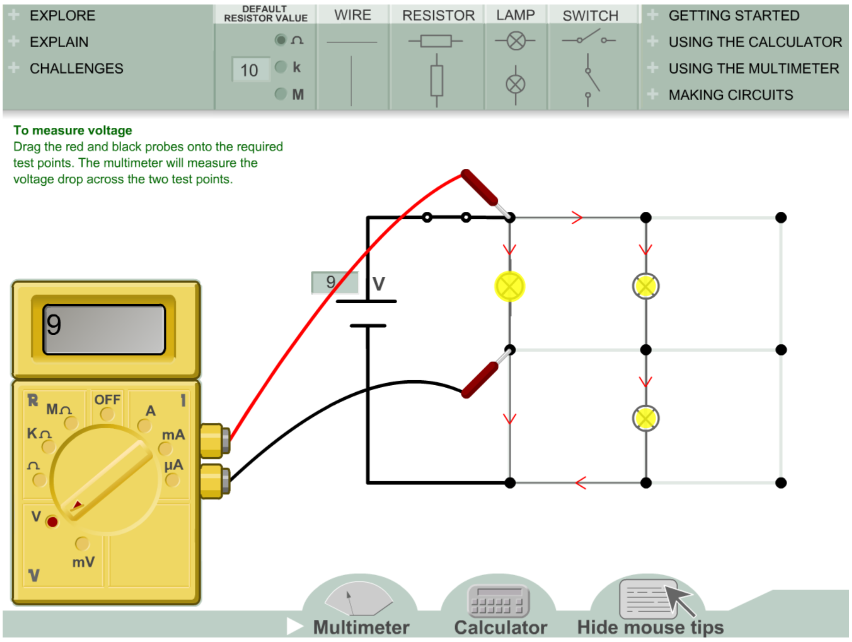

Figure 1. The electricity exploration tool is an easy-to-use simulation for constructing simple DC circuits, observing circuit functionalities, and conducting electrical measurement. Every operation is conducted by dragging and clicking with the mouse.

The representation level of EET is semi-realistic; it displays circuits schematically, but includes light bulbs with dynamically changing brightness (as the amount of current through the bulb increases, the yellow area inside the bulb becomes larger and the colour tone of that yellow changes, as well) and realistic measuring devices. The simulated model is authentic with two exceptions: Unlike real circuits, the wires have no resistance and the battery is always ideal (i.e. there is no change in the potential difference with time). This means that the simulation produces consistent output, which should make it easier for students to discover the underlying circuit principles **(M7, m)**. With EET, students are able to construct various DC circuits by using the mouse to drag wires, bulbs and resistors to the desired location in the circuits. After constructing the circuit or putting the circuit into a particular configuration, students can observe the effects of their actions and get instant feedback. They can, for instance, see whether the bulbs are lit and how bright they are, and what direction and which path(s) the current flows within the circuit (once a closed circuit is created, current flow is displayed by static arrows; this is something that cannot be observed in real circuits). They can also conduct electrical measurements with a multimeter by dragging its probes to the required testing points. EET can be replaced with another simulation with corresponding functionality and domain coverage (e.g: http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc) or with real equipment.

6. Conclusions

This deliverable has presented selection criteria for inquiry activities to be included in Ark of Inquiry and distributed to students across Europe via the Ark of Inquiry Portal. The criteria are based on a theoretical rationale and contemporary research evidence that are expected to support the selection of successful inquiry activities. The criteria consist of seven mandatory elements (Existing activity, Targeted age range 7–18, Focus on STEM domain, Support for inquiry type of learning, Coverage of at least one inquiry phase, Targeted for a specific inquiry proficiency level, Evidence on the success of the activity) and two recommended elements (Support for societal responsibility and Integration between learning content and inquiry skills). It is important to recognise that the range within each element of the selection criteria is so wide as a whole that a single activity that passes the criteria can (and shall) cover only part of the range (e.g., an advanced level activity that covers only three of the five inquiry phases). Therefore, in order to meet the needs of various learners and teachers, it is important to make sure that the selected activities as a whole will cover the ranges for the mandatory and recommended criteria as fully as possible.

The deliverable also presents criteria for describing the inquiry activities. The descriptions of inquiry activities and the selection criteria for the inquiry activities are closely interlinked, because the descriptions are means to transfer the actual selection criteria into a format (or vocabulary) that is visible and understandable to the end users. The descriptions become relevant once the selected inquiry activities are published in the Ark of Inquiry Portal, because they display a summary of each activity and provide a search filter that will help the users of Ark (i.e. students, teachers, and parents) to find and select activities that are (the most) suitable and engaging in a given context. The selection and description criteria are illustrated with an example that describes an inquiry activity with annotations of where and how the selection criteria are met.

Taken together, the selection and description criteria should help the project reach the goals set in the DoW by ensuring that the inquiry activities distributed and used within the project will 1) promote inquiry learning (and curricula) in STEM domains, 2) be productive and engaging for students at various age and skill levels, 3) be gender inclusive, and 4) promote students' awareness of societal responsibility.

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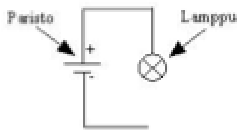
Appendix. Three worksheet examples.

Worksheet #1

Conceptualization / Hypothesis generation

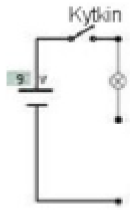
a) WITHOUT COMPUTER Look at the nearby pictures that present the same electronic circuit. What do you think, is the bulb lit or not?



☐ Bulb will lit ☐ Bulb won't lit

Investigation

b) WITH COMPUTER Let us test, whether or not your prediction was correct. Build the same circuit with the computer by dragging the bulb in to the correct place as instructed in the picture.

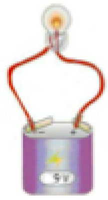


Is the bulb lit when the switch is open (up)? ☐ Yes ☐ No

Is the bulb lit when the switch is closed (down)? ☐ Yes ☐ No

Conceptualization / Hypothesis generation

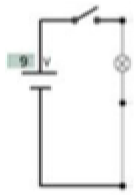
c) WITHOUT COMPUTER What do you think, is the bulb lit, if an additional wire is added to the circuit as shown in the picture?



☐ Bulb will lit ☐ Bulb won't lit

Investigation

d) WITH COMPUTER Test with the computer, whether or not your prediction was right by adding one cord to the circuit as instructed in the nearby picture.



Is the bulb lit when the switch is open (up)? ☐ Yes ☐ No

Is the bulb lit when the switch is closed (down)? ☐ Yes ☐ No

e) Measure the bulb voltage with the multimeter. The bulb voltage is........volts.

Compare the voltages between the battery and the lamp.

☐ The voltage of the lamp is the same as the voltage of the battery

☐ The voltage of the lamp is different than the voltage of the battery

Conclusion

f) What have you learned about the electrical circuits based on the above tasks? Bulb is lit when…(check whether or not the answer is correct or not)

	Correct	False
One wire is attached either from the + or the –pole of the battery to the lamp and the switch is up (open)		
One wire is attached either from the + or – pole of the battery to the lamp and the switch is down (closed)		
The wires are attached both from the + and - pole of the battery to the lamp and the switch is open		
The cords are attached both from the +pole and from the –pole of the battery tot the lamp and the switch is down		

Worksheet #2

Conceptualization / Hypothesis generation

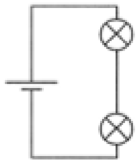
a) WITHOUT COMPUTER Predict what happens to the brightness of the bulbs if one bulb is added to the previous circuit as illustraded in the nearby pictures (2 bulbs in series). Check if you agree

☐ There is no change in the brightness of the bulbs

☐ The bulbs become brighter

☐ The bulbs become dimmer

☐ The upper bulb is brighter than the lower bulb



Investigation

b) WITH COMPUTER Test your prediction by constructing the circuit with the computer. Remember to push she switch down when you are ready. What do you notice (check if you agree)?

☐ There is no change in the brightness of the bulbs

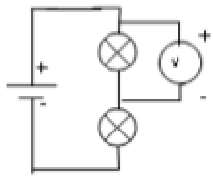
☐ The bulbs become brighter

☐ The bulbs become dimmer

☐ The upper bulb is brighter than the lower bulb

c) WITH COMPUTER Measure the voltage of the upper bulb of the circuit with the voltage meter as instructed in the nearby picture

The voltage of the upper bulb is .... volts.



d) WITH COMPUTER Now, measure the voltage of the lower bulb. The voltage of the lower bulb is .... volts.

e) What can you say about the voltages of the two bulbs?

☐ The voltages are the same ☐ The voltages are different

Conclusion

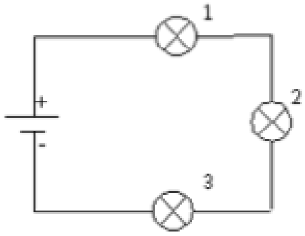
What can be said about the voltages of the lamps in comparison to the voltage of the battery in a two-bulb series circuit (check if you agree)?

☐ The voltage of a single bulb and the voltage of the battery are the same
☐ The voltage of a single bulb is half of the voltage of the battery
☐ The voltage of the battery is divided equally between both bulbs
☐ The total voltage of two bulbs is equal to the voltage of the battery
☐ The total voltage of two bulbs is half of the voltage of the battery
☐ The total voltage of two bulbs is two times the voltage of the battery

Worksheet #3

Conceptualization / Hypothesis generation

a) **WITHOUT COMPUTER** Predict what happens to the brightness of the bulbs if a third bulb is added to the previous circuit as illustraded in the nearby pictures (3 bulbs in series). Check if you agree



☐ There is no change in the brightness of the bulbs

☐ The bulbs become brighter

☐ The bulbs become dimmer

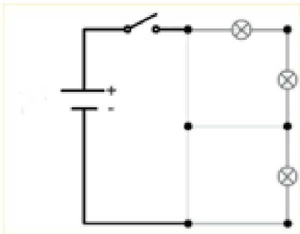
☐ The 1st bulb is brighter than the 3rd bulb

b) **WITHOUT COMPUTER** Predict, what will happen to the voltages

☐ Nothing changes
☐ Voltage will increase
☐ Voltage will decrease

Investigation

c) **WITH COMPUTER** In order to test the success of your predictions, build the circuit with the computer (remember to close the switch). What happened to the brightness of the bulbs?



☐ There is no change in the brightness of the bulbs

☐ The bulbs become brighter

☐ The bulbs become dimmer

☐ The 1st bulb is brighter than the 3rd bulb

d) **WITH COMPUTER** Measure the bulb voltages (V).

1. bulb: _______ volts, 2. bulbs. ________ volts, 3. bulb: _________ volts

Conclusion

e) What can you conclude about the principles of series circuits based on the worksheet 1 to 3?

	Correct	False
1. The bulb closest to the +pole is brighter compared to other bulbs		
2. Total voltage of the bulbs is the same as battery voltage		
3. Adding a new bulb will decrease the voltage of existing bulbs		
4. Adding a bulb will make all the bulbs brighter		
5. Adding a bulb will make the bulbs brighter		
6. The bulb closest to the -pole is dimmer compared to other bulbs		
7. Location of a bulb has no effect on its brightness		
8. Within a given series circuit all bulbs will be equally bright		
9. Within a given series circuit all bulbs will have identical voltages		
10. The battery voltage will divide evenly across the bulbs		