Ark of Inquiry: Inquiry Activities for Youth over Europe

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Scientific Evaluation Report of Implementing Ark of Inquiry

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Summary

The present deliverable presents the results of the evaluation activities that have been carried out during the large-scale implementation phase of the Ark of Inquiry project. As originally planned and reported in Deliverable D5.2, the evaluation activities of the present project were built around the implementation of 6 studies. The six studies served the function of delimiting the scope of evaluation. While most of the evaluation activities were based on studies done in single countries, these are the conclusions that we can derive from the six studies conducted: teachers profitably used the instruments developed during the project by becoming designers, which allowed them to adapt the different materials to their own context (Study 1); the teacher training course conducted during the project encouraged teachers to take a positive stance towards inquiry learning and increased their sense of efficacy in applying it (Study 2); the teacher training course format supports the development of pre-service teachers' inquiry competence (Study 3); inquiry learning can give teachers the opportunity to develop Responsible Research and Innovation, when pupils are given the responsibility to make decisions in the different phases of an inquiry (Study 4); the Ark of Inquiry activities are a useful resource and can be well adapted to the teaching of 21st century skills and RRI (Study 5); inquiry activities, overall, are able to elicit the interest of pupils and have the potential to increase pupils' interest in learning and studying science subjects and contents (Study 6).

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1. Introduction

This deliverable presents the results of the evaluation activities that have been carried out during the large-scale implementation phase of the Ark of Inquiry project. As originally planned and reported in Deliverable D5.2, the evaluation activities of the project were built around the implementation of 6 studies. The six studies served the function of delimiting the scope of evaluation.

As we reported in Deliverable D5.2, the evaluation activities focused on three main objects. The first object of evaluation concerned the instruments for supporting teachers that were developed in WP 1 (the so-called “evaluation tool-box” for teachers) and in WP2 (the repository of inquiry activities). The studies that addressed this object of evaluation were Study 1, Study 5 and Study 6. Study 1 chiefly focused on how teachers adapted the evaluation tool-box. Study 5 and 6 focused more on the inquiry activities. More specifically, they focused on the impact that inquiry activities had on pupils.

The second object of evaluation concerned the teacher training course format devised in the project. In this case two studies were involved, namely, Study 2 and Study 3. Study 2 focused specifically on the Ark of Inquiry teacher training courses that were conducted during the implementation of the project in the 12 different countries involved in the Ark of Inquiry project. Study 3 investigated how to design a course that would enhance prospective teachers’ inquiry competence, and provided evidence as to the benefit of such training format.

The third object of evaluation concerned RRI and its relations to inquiry learning. The studies which addressed that were Study 4, Study 5 and Study 6. Study 4 had the major goal of exploring how inquiry learning can be used for the promotion of Responsible Research and Innovation. Studies 5 and 6 aimed at investigating if the inquiry activities used by teachers in their class 1) had a positive effect on engaging pupils in doing science and 2) could be used for the promotion of the 21th century skills.

Table 1 provides a summary of the evaluation activities undertaken and the main topics of the six studies conducted.

Table 1. Evaluation Plan Summarized.

Title of the study	Leading partner	Object(s) of evaluation
Teachers as designers: adaptive use of the Ark of Inquiry	HAN	Instruments for supporting teachers;
Teachers’ readiness to use the inquiry approach in their classroom	UT	Teacher training course

Designing a Course for Enhancing Prospective Teachers' Inquiry Competence	UCY	Teacher training course
Inquiry learning as a pedagogical framework for promoting Responsible Research and Innovation as a way of making sense of science in and for society	UT	Inquiry cycle model and RRI
Incidence of 21st century skills and competences and RRI in Ark of Inquiry activities	UTU	Instruments for supporting teachers, RRI
Engaging learners: exploring inquiry activity potential for triggering and maintaining interest	UTU	RRI, instruments for supporting teachers

While we have tried to maintain scientific rigor in conducting the studies, in presenting the main findings we have tried to use a style accessible for those people that are working outside the academia. Or that may not be particularly familiar with the kind of jargon and style employed in academic research. Such a decision is based on the fact that in writing the reports of the 6 studies we specifically address teachers and educators. Each and every study ends with specifying its main practical implications for teachers and educators. It is worth mentioning that in some cases the text presented is an adaptation from material that has been published in international journals. We invite those who would like to know more about the studies to turn to the corresponding publications.

The deliverable is structured so as to give ample space for the presentation and discussion of the results of the 6 studies. So, every study contains a brief introduction describing the context and purpose of the study, a methodological section describing how data was collected, the results part, and a final part devoted to eliciting the main practical implications for teachers and educators.

While most of the evaluation activities were based on studies carried out in single countries, these are the more general conclusions that we can draw:

1) Teachers profitably used the instruments developed during the project by becoming designers, which allowed them to adapt the different materials to their own context (Study 1).
2) Overall, the teacher training course conducted during the project encouraged teachers to take a positive stance towards inquiry learning and increased their sense of efficacy in applying it (Study 2).
3) The teacher training course format supports the development of pre-service teachers' inquiry competence (Study 3).
4) Inquiry learning can give teachers the opportunity to develop Responsible Research and Innovation, when pupils are given the responsibility to make decisions in the different phases of an inquiry (Study 4).

5) The Ark of Inquiry activities are a useful resource and can be well adapted to the teaching of 21st century skills and RRI (Study 5).
6) Inquiry activities, overall, are able to elicit the interest of pupils and have the potential to increase pupils' interest in learning and studying science subjects and contents (Study 6).

In order to facilitate the navigation through a long and, to some extent, heterogeneous text, we present in Table 2 the summary of each of the 6 studies.

Table 2. Summary of the Six Studies

Title	Summary
Teachers as Designers: Adaptive Use of the Ark of Inquiry	The Ark of Inquiry seeks to support inquiry-based science education (IBSE) in different countries and school systems across Europe by teachers that may differ in their prior experiences with IBSE. Given the differences, the assumption is that teachers need to make adaptations to the approach and materials of the Ark of Inquiry. This study follows 20 primary school teachers from the Netherlands as they apply the Ark of Inquiry approach and materials in their classrooms and seeks answers to the research questions of if, how and why teachers make adaptations to the approach and materials. The collected data include lesson plans and diaries of the teachers before and during the implementation, and group interviews held with the teachers afterwards. The findings show that teachers appreciate and successfully implement the three core elements of the approach (a five phase inquiry cycle model, formative evaluation, and RRI). While doing so, teachers frequently adapt materials to their own and their pupils' needs. Examples of adaptations are changing the activity level, adjusting evaluation instruments, and adding creative components to activities. Reasons to make adaptations are both practical (e.g., time constraints, classroom management) and pedagogical (e.g., preferring group work, alignment with age and capacities of pupils). From this study, it is concluded that the Ark of Inquiry approach and materials provide a rich and relevant starting point for further adaptation. The outcomes support the idea that turning teachers into designers by promoting and supporting adaptation strengthens successful local implementation and gives ample opportunity for professional development.
Teachers' Readiness to Use the Inquiry Approach in Their Classroom	The use of inquiry learning is encouraged in schools because it has been shown to be an effective method for raising pupils' motivation in STEM subjects. Nevertheless, inquiry learning is not very often used in classrooms. Within the Ark of Inquiry project teacher training sessions were designed that enabled the teachers to experience inquiry learning from different perspectives: teacher as a learner, teacher as a thinker and teacher as a reflective practitioner. The trainings were expected to have an impact on teachers' sense of efficacy, which has been shown to be positively related to teachers' readiness to adopt new teaching methods and reducing perceived obstacles when implementing inquiry learning. Four hundred and ninety seven teachers from 10 countries participated in the study. We found that teachers' higher sense of efficacy was related to more positive attitudes towards inquiry learning. In addition, after the teacher training sessions, the teachers felt, on average, that they were able to engage pupils to a larger extent. Also, their attitudes towards inquiry learning changed for more positive. The strongest positive effects on attitudes were related to the perceived available resources for teaching inquiry and inquiry learning being suitable for motivating different pupils. However, the training did not impact how teachers perceive systemic restrictions (e.g., related to curricula). It is concluded that this kind of teacher training can be a suitable method of boosting teachers' sense of efficacy and overcoming some perceived obstacles for adopting inquiry learning in the classroom.
Designing a Course for Enhancing	The purpose of this study was to investigate the effect of a professional development (PD)

Prospective Teachers' Inquiry Competence	programme on pre-service teachers' development of inquiry competence (inquiry skills, definitions of inquiry, pedagogical content knowledge for teaching science as inquiry). Our approach drew on constructivist learning and situated cognition, built upon nine critical features of effective inquiry PD, and made use of an inquiry learning framework reported in the literature. The participants were 72 pre-service elementary teachers enrolled in a science method course, within which the PD programme was implemented. The course was split in three phases. During Phase 1, teachers as learners engaged in multiple inquiry cycles through a specially designed curriculum. During Phase 2, teachers as thinkers studied the curriculum from its pedagogical rationale, whereas during Phase 3, the teachers as reflective practitioners designed and implemented lesson plans and curriculum materials for the preparation of a science fair project. The constant comparative method and open coding were used for analysing the data collected from teachers' definitions of inquiry, reflective diaries, pre- and post-assessment of teachers' inquiry skills, science fair project work, and end-of-course individual interviews. The findings revealed that a significant number of pre-service teachers shifted from naive to advanced inquiry competence, indicating that the format and structure of the course, in conjunction with the curriculum materials and the teaching approach, significantly influenced pre-service teachers' inquiry skills, definitions of inquiry, and pedagogical content knowledge for teaching science as inquiry. Implications of the findings are discussed in light of how to best support pre-service teachers in teaching science as inquiry.
Inquiry Learning as a Pedagogical Framework for Promoting Responsible Research and Innovation as a Way of Making Sense of Science in and for Society	Originally introduced in several policy documents issued by different institutions belonging to the EU (European Union), the term Responsible Research and Innovation (hereafter RRI) has gained considerable attention in recent years among researchers coming from different backgrounds and disciplines. RRI constitutes an attempt to articulate a theoretical framework that would shape the governance of science in Europe. While science education is mentioned in various EU policy documents as one of its strategic dimensions, the way in which RRI can actually be translated into science education is a topic that needs empirical investigation as well as theoretical elaboration. The overall aim of the study is precisely to offer that. In the present article we posit that RRI in science education can be experienced meaningfully by linking it to inquiry learning, which already stresses the importance of active participation as well as pupils' responsibility for discovering knowledge. In order to see this potential connection in practice, we conducted an ethnographic study involving seven Estonian science teachers, who agreed to be observed at least three times when they conducted inquiry learning lessons in their school. Specifically, the study aimed at acquiring a better understanding as to the meaning that the term *responsibility* can have during the different phases of inquiry learning lessons. The results of the ethnographic study allow us to come to the conclusion that RRI can be interpreted in science education as a type of meaningful engagement *in* and *for* an inquiry during which pupils are given the opportunity to make *meaningful* decisions in the different inquiry phases and thus be able to take responsibility for the inquiry process.
Incidence of 21st Century Skills and Competences and RRI in Ark of Inquiry Activities	As the world has undergone rapid changes during the past few decades, it is clear that education and schooling need to respond and adapt accordingly. Twenty-first century skills and RRI have in recent EU policy reports (e.g., Hazelkorn et al., 2015) been highlighted as increasingly important educational contents, which, according to previous research (e.g., Gordon et al., 2009; Shear, Gallagher, & Patel, 2011), can effectively be taught through an inquiry learning approach. The main purpose of this research was, therefore, to create an assessment tool for evaluating how well Ark of Inquiry activities cover 21st century skills, including RRI contents. The assessment tool was created based on a content analysis of five widely used 21st century skills frameworks. The main outcomes of this research entail a description of the created synthesis of 21st century skills frameworks and the created assessment tool for evaluating inquiry activities from the perspective of 21st century skills in addition to the results of the assessment of the inquiry activities of the Ark of Inquiry project. The results indicate that Ark of Inquiry activities are a useful resource and can be well adapted to the teaching of 21st century skills and RRI even though some variation was found between the activities in how well they cover different 21st century skills.

Pupils' On-task Interest While Conducting Various Inquiry Activities	The study reports about the outcomes of research on pupils' on-task interest in inquiry learning during an inquiry activity. Data on pupils' on-task interest was gathered from 2757 pupils from eight Ark of Inquiry partner countries by using an analysis framework based on the previous work of Tapola, Jaakkola, and Niemivirta (2014). To investigate the possible change in pupils' interest, pupils were asked to fill in the questionnaire at the beginning of the first inquiry learning session, while they were working with the activity, and at the end of the last session. The results of this research are based on two measurements, pupils' ratings at the beginning and at the end of the activity. The results of this study showed that inquiry learning seems to be highly interesting in account of pupils. The overall average of pupils' on-task interest, rated on a scale from 1 to 7, was 5.55 (SD=1.40). There was a significant difference in the level of interest between the first and the last measurement, with the level of interest rising while conducting inquiry activities. When taking a look at the genders and the two age groups, a significant difference was found between males and females at the beginning of the inquiry activity, with females expressing a higher on-task interest than males. Based on our results, the difference between genders did, however, diminish during the activity, and no significant differences were found at the end of the last activity session. Considering the two age groups created for the analysis, the younger pupils expressed a higher interest in the inquiry activity compared to the older pupils. More broadly, inquiry learning does appear interesting for pupils and has potential for increasing pupils' interest in learning and studying science subjects and contents.

2. Study 1. Teachers as Designers: Adaptive Use of the Ark of Inquiry[1]

2.1. Introduction

In general, teachers have been found to be a crucial factor in the implementation of any innovation (Brown, 2009; Doyle & Rosemartin, 2012). School reform and sustainable curriculum renewal highly depend on teachers' willingness and capacity to adopt and implement new approaches and materials (e.g., Evans, 2008). First, teachers need to perceive the innovation as relevant to their daily practices. They need to experience 'a need for change' that is met by the innovation and develop the attitudinal wish to explore the innovation further. Next, teachers need to feel they are able to implement the innovation in terms of their own abilities as well as the circumstances under which they do their work. If they think they are not, they need to be able to receive training and/or (contextual) support.

Moreover, teachers have been found to frequently adapt innovations to local insights and needs (Barab & Luehmann, 2003, Rogers, 2003). Curriculum innovations are often too general to be ready to be applied in any classroom. Westbroek et al. (2016) argue that factors such as subject matter knowledge, pedagogical content knowledge, beliefs and contextual matters all influence the implementation. Curriculum innovations and new materials deviate from existing daily practices and put forward new affordances and constraints to existing classroom ecologies (Doyle & Rosemartin, 2012). They need to be adjusted to fit the many and sometimes contrasting issues that teachers face. This raises the question as to whether teachers' adaptations do justice to the original principles of the design, contradict them, or are compatible with them. In light of this question, the fidelity of implementation measures if and how teachers adapt materials at the cost of its principles or do so remaining within the margins of flexible usage, leaving the pedagogical approach intact (O'Donnell, 2008).

In search of a better understanding of the adaptations teachers make to new curricula, Doyle and Rosemartin (2012) conclude that teachers work in a complex classroom ecology and need to be able to bridge theoretical underpinnings and concrete tasks of new curricula to the multidimensional classroom in which many interpersonal relationships are present that further afford or constrain innovations. They call this the 'ecology of enactment', in which teaching could best be seen as an act of designing in which teachers are obliged to

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[1] Modified and adapted from: De Vries, B., Schouwenaars, I., & Stokhof, H. (2017). Turning teachers into designers: The case of the Ark of Inquiry. *Science Education International, 28*(4), 246-257.

actively relate to new curriculum materials by selecting and interpreting (parts of) materials, reconciling them with their own and their pupils' beliefs and needs, and, if necessary, by changing them to facilitate their pupils' learning (cf. Brown, 2009). Many others have pointed out that teachers should be viewed as designers in the process of adopting and adjusting new curriculum approaches and materials (e.g., Barab & Luehmann, 2003; Davis et al, 2011).

One of the aims of the Ark of Inquiry is to support inquiry learning in different countries across Europe. In practice, this means that the Ark of Inquiry has to function in a variety of, even fundamentally different, school systems and school curricula. Also, the Ark of Inquiry has been developed for use in three totally different contexts: primary education, secondary education and home. In addition, teachers who come to use the Ark of Inquiry probably differ both in appreciation of the worth of inquiry-based science education (IBSE) and in the range of prior experience of implementing its various forms. This leads to the expectation that teachers will need to make local adaptations to the approach and materials provided by the Ark of Inquiry.

Early impressions of teachers exploring the Ark of Inquiry platform indeed confirmed that teachers want to adopt and implement the Ark of Inquiry materials according to their own needs and prior experiences (De Vries, 2016). For instance, teachers who are used to doing inquiry learning in collaborative settings adjusted the Ark of Inquiry activities and evaluation instruments in such a way that their pupils could work with it in groups. And teachers who were not familiar with formative assessment sought ways to practice it on a small scale by selecting only parts of the toolbox and adjusting its procedure, instead of using its full potential. This study aims to explore in more detail what triggers teachers' need for adaptation and investigate if and how the Ark of Inquiry materials support adaptation to local needs. After outlining what educational design theories have said about curriculum innovation and adaptation, we present findings from a multiple case study conducted in the Netherlands on teachers' decisions and reasons to make adaptations.

To summarize, implementation is a complex process in which teachers face many challenges to align the innovation to other goals they pursue, such as keeping management procedures and structures in their classrooms and attaining the curriculum goals. Given the complexity of successful implementation, many educational researchers and developers have argued that adaptation of new approaches and materials is the rule rather than the exception and teachers need to be acknowledged as designers of enacted curricula. The aim of the Ark of Inquiry is to promote inquiry-based science education (IBSE) in many different contexts. It is therefore expected that teachers who start using the Ark of Inquiry platform will need to (re)design its approach and/or materials to align them with local needs, preferences and circumstances. In the study described in this chapter, the implementation of the Ark of Inquiry approach and materials in several primary schools in the Netherlands is described and the question is raised *if, how, and why the teachers adapt the three elements of the Ark of Inquiry approach and/or its materials*.

2.2. Methodology

Ark of Inquiry approach and materials

The approach of the Ark of Inquiry is viewed to consist of three main elements: a five phase inquiry cycle model (Pedaste et al, 2015), formative assessment of inquiry proficiency, and a focus on Responsible Research and Innovation (RRI). In the Ark of Inquiry platform the approach was translated into a framework of inquiry proficiency describing the subskills of inquiry and RRI in five phases of inquiry and at three levels of proficiency: A, B and C level. The materials provided include inquiry activities, a toolbox containing formative assessment instruments, and a pedagogical scenario that promotes and guides the design of RRI activities. Table 1 gives an overview of the approach and materials of the Ark of Inquiry. The approach and materials have been described and argued extensively in earlier deliverables on the inquiry approach (D1.5), evaluation (D1.6) and the award system (D1.3) of the Ark of Inquiry (see De Vries, 2015; De Vries, 2016; Siiman & De Vries, 2016).

Table 1. Approach and Materials of the Ark of Inquiry

Elements of the approach	Materials for teachers and pupils
Five phase inquiry cycle model	Schematized inquiry activities
Formative evaluation	Framework of inquiry proficiency (A, B, C level skills of inquiry and RRI) Evaluation toolbox containing self-evaluation instrument, peer feedback instrument, formative dialogue instrument
Focus on RRI	Pedagogical scenario to design RRI activities

Participants and procedure

In total, 25 teachers from 19 Dutch primary schools participated in this study. Sixteen teachers worked in different schools residing under the same board. Nine teachers came from two teams of schools located in the same neighbourhood. All teachers volunteered to participate. In total, over 500 pupils were represented by the teachers, the pupils' age ranging from 4 to 12 years old. All teachers had some experience with IBSE. Sixteen teachers had been trained in previous years to become science education specialists in their schools and could be considered experienced users and designers of IBSE. Nine teachers could be considered moderately experienced in IBSE. Formative evaluation of inquiry proficiency and RRI were new to all of the teachers.

The participants took part in an initial training, implemented one or more inquiry activities in their classrooms and attended a second meeting to reflect on their experiences in small groups. A semi-structured interview protocol was used to structure the conversation. The content of the training was adapted from training materials provided by the Ark of Inquiry (see D4.2, Papaevripidou & Zacharia, 2016). Because the teachers were experienced in practising IBSE in their classrooms, the training focused on turning teachers into thinkers and reflective practitioners and strongly considered teachers' roles as designers: the teachers were invited and triggered to translate Ark of Inquiry elements and materials into lesson plans for their own classrooms.

Data collection and analysis

To gain insight into teachers' choices and reasons for adoption and adaptation, the following data were collected: (1) informal field notes during the training session, (2) lesson plans and diaries in which the teachers noted their decisions and reflections during designing and implementing the inquiry activity, (3) group interviews during the second meeting of the training in which the teachers shared their experiences and reflections.

Data analysis was conducted in several steps aiming at getting an overview of the kind of activities the teachers used and the amount of adaptations they made, and gaining insight into teachers' experiences. First, lesson plans and materials were described in terms of subject, level, and if and which adaptations were made by using Van den Akker's (2003) spider web for design, which discerns the following: goal, content, activity, teacher's role, materials, grouping, duration, location, and assessment. Next, statements from the diaries were categorized as related to (1) inquiry learning and activities, (2) evaluation of proficiency, or (3) RRI. The statements consisted of answers to open questions in the diary format and varied in length from several sentences up to a few pages. Finally, statements from the seven group interviews, which covered a total of 46 pages of transcriptions, were categorized as statements about inquiry, evaluation, and RRI. Then, a closer look within the categories led to subgroups on specific phases and pupil behaviour.

2.3. Results

Overview of activities designed: use of the five phase inquiry cycle model

In general, it was observed that the teachers used the inquiry cycle model to structure the activity, define parts of the lesson and focus on one or several phases. Some teachers explained that the model helped them to pay increased attention to parts of the inquiry process, for instance by designing more extended orientation and discussing the phases. For instance, one teacher teaching grade 7 explained, "In education we are used to present learning goals at the start and discuss if we reached them at the end. By planning more time at the end by discussing the experiments I discovered that my pupils thought through the experiments and came to conclusions more than I expected. It was nice to see that by discussing findings, deeper understanding was reached related to learning goals." Another teacher, a kindergarten teacher, explained an increased function of the orientation phase, "We spent quite some time to the orientation phase. The pupils spent time just watching the small animals and experienced how much there are of them in the ground, in the water, in the air. And what is an insect, not all small animals are insects. And only after they did that, we asked the pupils to start formulating questions." Some teachers reflected on the model by explaining they already recognized the phases from other inquiry models. As one teacher (grade 7) put it, "What I think is most important is that you have an overview of the process. We learned that before, so I recognize new things, different wordings. It just uses slightly different terminology, and it works a little bit different."

Three activity types were realized: engineering, experimenting, and guided discovery. The engineering activities were aimed at letting pupils design, build and evaluate a construction. Examples of engineering activities were building an amusement park attraction, building a boat, and designing the ideal cage for an animal. Teachers designed the engineering activities themselves and rated them at level C. The engineering activities often took the form of long-running projects that the pupils worked on for several hours a week over several weeks. In contrast, the experimenting activities came from existing sources. They were rated at level A because of their structured nature, and pupils conducted the experiments during shorter lessons or a short series of lessons during one school day. Examples of experimenting activities were the Egg in the bottle and Floating experiments, taken from the Ark of Inquiry platform and a science education syllabus, respectively. The guided discovery activities, finally, took the form of a series of lessons or projects in which teachers pre-structured the discovery process of their pupils in a loose way and with enough space to improvise. These activities typically contained structured as well as open subtasks and were therefore rated at B level. Guided discovery was frequently found in kindergarten and in lower grades. Guided discovery was characterized by open goal settings and often moved along by pupils' own questions that spontaneously arose after being introduced to the general topic. In contrast, engineering and experimenting have set goals from the beginning. Table 2 gives an overview of types of activities and the main characteristics found in the data set.

Table 2. Enacted Curriculum: Types and Characteristics of Activities

Types of activities	Characteristics	Examples
A level experimenting (N=5)	Short lesson / series of lessons Existing activity from Ark of Inquiry, method or web source	Egg in the bottle, floating or sinking, experiments about air / air pressure
B level guided discovery (N=11)	Series of lessons, project Designed by teacher(s)	Getting to know the brain, discovering the sea world, life at a camping site
C level engineering (N=9)	Project Designed by teacher(s)	Building a boat, building an amusement park, building a planet

The model presented teachers with an overview of sub-phases and proficiency levels, and this overview seems to have promoted and supported adaptation in the sub-phases of the activities. In several ways, adaptations to (the levels of) activities were made. The teachers had practical and pedagogical reasons to make adaptations, such as time constraints and alignment with pupils' capacities, respectively. First, teachers added extra materials designed by themselves or taken from other sources. For instance, they designed worksheets through which pupils could address important questions. By doing so they sometimes changed the level from B/C to A. In other cases the opposite occurred. For instance, teachers added creative subtasks as a result of which the activity became more open and ill-structured. A second way in which activities and/or levels were changed was by combining different levels in one activity. In some engineering projects the teachers used experimenting in the Orientation phase to introduce the topic, whereas in the following phases an ill-structured design problem was put central. Likewise, some experiments ended in open investigations or with open discussion on the implications. The teachers were aware of level differences between inquiry phases and in their lesson plans applied level allocation per phase.

Moreover, the five phase inquiry cycle model also seemed to help teachers in observing what pupils actually do in different parts of the activity. Some teachers reflected in their diaries on what pupils actually did while performing the activity and sometimes recognized an uncharacteristic behaviour for the level of activity in a specific phase. For instance, one teacher doing the *Egg in the bottle* experiment with her pupils, which she rated as an A level activity, noticed a girl who was able to explain and discuss the experiment without any help from the teacher and was better able to formulate questions and conclusions than the other pupils in the classroom. The teacher concluded in her diary that although the activity and group level was A, this girl performed at B level.

Formative evaluation

Formative assessment in the context of IBSE was new to all teachers except one. Overall, the teachers reacted positively when presented with the general idea of formative evaluation and the concrete materials in the toolbox. During the training, the teachers explored the three basic types of formative assessment provided by the toolbox – formative dialogue, self-evaluation and peer feedback – and started planning what they would like to use in their classrooms. From the designs, diaries and interviews it becomes clear that almost all the teachers started using one or more formative evaluation tools in their classrooms. Furthermore, the data show that the teachers redesigned the basic forms of the toolbox into adapted instruments and personalized ways of usage. The teachers made many adaptations to the original tools by adapting the formats and/or the way they were used (timing and setting). Table 3 gives an overview of the methods/instruments used by the teachers.

Table 3. Enacted Curriculum: Methods and Instruments of Formative Evaluation

Evaluation Method	Instruments	Examples of usage
Formative dialogue (N=10)	Open conversation	Conversation with one pupil; whole class / group discussions in Orientation and Discussion phase; whole class / group discussions in all phases
Self-evaluation (N=7)	Adapted self-evaluation form Form from other method	Annotated photo; Likert scale scores; part of portfolio; computer-based administration
Peer feedback (N=9)	Open conversation protocol Object presentations Peer feedback form	Tips & Tops; presenting and discussing designs; small group conversations

It was observed that although the Ark of Inquiry aims at developing inquiry proficiency, the teachers hardly defined learning goals related to inquiry proficiency. Mostly, learning goals related to the domain and subject were explicitly addressed in the Orientation and Discussion phase. In the engineering activities, for instance, design products were tested and discussed. Only incidentally, some teachers did successfully pay attention to specific subskills as learning goals at the beginning or end of an activity. One subskill relatively often mentioned by teachers was 'how to formulate a research question and hypothesis'. Other subskills related to inquiry proficiency that were accidentally paid attention to regularly were 'looking up information in books and websites' and 'working in groups'.

Several observations illustrate that the teachers did not succeed in effectively using the evaluation tools to address inquiry proficiency more structurally. First, many teachers performed the formative dialogue without a protocol. Instead, they held open conversations. Without a protocol to structure the conversation, it mainly wandered around domain and subject instead of inquiry proficiency. Second, usage of the self-evaluation and peer feedback forms was embedded in local rituals such as using an existing format, or integration with a portfolio approach or local computer system. Most of the local rituals were aimed at evaluating content rather than process. One reason that the teachers mentioned for not paying much attention to inquiry proficiency was that their pupils found it difficult to reflect on their learning processes. As one teacher (grade 4) put it, "My pupils still need to learn to observe themselves as learners and ask questions." Similarly, another teacher (grade 3) experienced her pupils to be too young to have reflective discussions about the process of inquiry. In her interview she explained, "I was a teacher in grade 5 last year. It was easier to discuss processes with them than with pupils in grade 3. They are more critical. I asked my pupils what they liked in the inquiry process and they only answered 'everything' and could not explain in more detail what they liked most."

RRI

Half of the teachers realized an RRI activity. RRI was realized across all grades. The teachers designed RRI discussions during the Orientation phase at the start of the inquiry activity or during the Discussion phase at the end. Addressing RRI always took the form of a whole class discussion in which questions about the relevance as well as consequences and ethics of research outcomes were discussed. The teachers said they were inspired to do so by the pedagogical scenario of the Ark of Inquiry platform and most of the teachers that realized an RRI activity used this scenario to adapt the activity. Examples of RRI activities are, for example, letting pupils explore their living environment to gain ideas about suitable forms of tourism in areas where many people live; exploring how principles behind 'egg in a bottle' could be used in transportation; sharing stories about muscle illness in pupils' own living environment; and discussing the ethics of working with animals and discussing the fact that experiments can also fail. To a lesser extent, RRI activities were also used to raise the metacognitive awareness of the processes, pitfalls and merits of scientific inquiry, but this was rare. The cases do show how RRI can be addressed by exploring or discussing small topics derived from grand challenges even with pupils at very young ages. The teachers who did so experienced that RRI can be included in the design of an inquiry activity rather easily: "With all we do a bridge can be built to recent news items or a larger theme. And before you know it, a discussion is started" (teacher, grade 4). An illustration of the ease with which some teachers seem to build such bridges is the following fragment, taken from a series of lessons on small animals and insects: "We also discussed the ethics, which I found very important because you work with living creatures. So we first explored how we should deal with living creatures in the classroom, what do they need to survive? And if we leave them in the classroom, shouldn't they eat something? Think about yourself, you would not be able to sit in a box for a week without any food. Then we discussed being respectful, and we ended up deciding that one group of pupils should dedicate their time to feeding them properly and in time" (teacher, grade 5). Overall, many teachers reported pupils' eagerness to discuss societal issues (for instance, about keeping animals in cages) and their willingness to share personal stories related to the subject.

From the data it becomes apparent that many teachers could relate rather easily to the definition and goals of RRI and find it important to make inquiry meaningful for pupils. At the same time, half of the teachers expressed difficulties designing and realizing RRI activities in their classrooms for several reasons. Some experienced lack of time, others found it difficult to relate the inquiry activity to the grand themes suggested in the pedagogical scenario. The latter was mostly felt by teachers who implemented an experiment (A level activity).

2.4. Practical relevance

In the study presented in this chapter, the question is raised *if, how, and why teachers adapt the three elements of the Ark of Inquiry approach and/or its materials*. The teachers who participated in this study were moderately to highly experienced users and designers of IBSE. In general, they were motivated to adopt the approach and implement the materials in their practices and did so successfully. In the process of designing and preparing their lesson plans, the teachers used the five phase inquiry cycle model to structure the activities and hence successfully implemented the model in the activities and materials used. They worked with the levels of inquiry proficiency to describe, implement and reflect on their lessons in more detail. At the same time, the findings show that in the case of formative evaluation and RRI many teachers did not successfully implement those core elements. Related to formative evaluation, it is concluded that in many cases, the teachers adapted the evaluation tools in such a way that the focus changed from process-oriented to content-oriented. It is concluded that although formative evaluation of inquiry proficiency is adopted by the teachers at the intended curriculum level, it is not yet realized in their designs and implementations. Related to RRI, it is concluded from the data that about half of the teachers easily embedded an RRI activity in the Orientation and/or Discussion phase of the inquiry activity, addressing bigger themes and questions with their pupils. The teachers used the pedagogical scenario to prepare the RRI activities. The RRI activities took the form of whole class discussions on the relevance, consequences and ethics of research outcomes. However, half of the teachers found it difficult to realize RRI activities and explained this by time constraints, pupils' age, or nature of the inquiry activity.

It was found that teachers had several reasons to adapt the materials. Some of the reasons that were frequently mentioned were tailoring the materials to their pupils' needs, aligning the materials with existing practices and tools in the schools, or practical reasons, such as saving time and/or making them easier to use. The study shows that the Ark of Inquiry approach and materials successfully invite and support teachers in realizing IBSE in their classrooms in their own preferred ways. Both the Ark of Inquiry approach and materials as well as the nature and setup of the teacher training sessions seem to have successfully supported teachers in becoming designers of their own inquiry-based science education projects.

Implications for teacher training and professional development

In this chapter we have reasoned and demonstrated that the implementation of new curricula in daily practices is always a matter of adoption *and* adaptation and never a matter of adoption alone. As such, the study could be seen as an illustration of how teachers move from an intended curriculum consisting of its approach and materials towards a realized curriculum in classrooms (cf. Van den Akker, 2003). It seems reasonable to conclude that in the process of adopting an intended curriculum to a realized curriculum, some things are gained and some are lost. In this study, many gains were observed such as the ease with which the teachers and pupils moved from A level activities to more open problem statements at B and C levels. These seemed to be a more natural environment for them than many more structured A level activities. Likewise, we observed the natural implementation of dialogue as a way to evaluate and discuss inquiry outcomes, half of the time from creative RRI perspectives. From a practical point of view the gains illustrate the importance of providing teachers with opportunities to experiment with new curricula so that they can start professional development in their own classroom environments and, secondly, that those opportunities should revolve around becoming designers of local curriculum implementation (cf. Carlgren, 2011). For that purpose, it seems essential that approaches and materials provided are open sources that are easily accessible and open to adaptation (cf. Brown, 2009). Teachers can then develop their pedagogical design capacity instead of simply learning to use specific fixed curriculum materials.

But we also saw some losses. The main one may be the lack of focus on inquiry proficiency in evaluation activities. Although all the teachers adopted the idea of formative evaluation of inquiry proficiency in the intended curriculum, they found it hard to realize. The hidden curriculum (Denscombe, 1982), defined as the (often implicit) norms and values a school or a teacher holds, might be of influence in the transition from intended to realized curriculum and further research could integrate this perspective to explain teachers' decision making in the process of adaptation. Also, an interesting perspective is provided by Smith et al. (2013), who suggest that teachers need Pedagogical Process Knowledge (PPK) to realize (scientific) inquiry learning. Complementary to Pedagogical Content Knowledge, they define PPK as the knowledge and skills that teachers need to support their pupils in developing certain ways of working and thinking, such as scientific inquiry. It seems to be precisely this PPK on scientific inquiry that teachers need to help their pupils become aware of the phases and skills involved. If the teachers lack PPK, they can use the five phase inquiry cycle model (implicitly) in their designs but not yet in their conversations with pupils to stimulate their metacognitive awareness. From a practical point of view this would suggest that teacher training should emphasize PPK explicitly and profoundly.

2.5. References

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3. Study 2. Teachers' Readiness to Use the Inquiry Approach in Their Classroom[2]

3.1. Introduction

Description of the general purpose of the study

Most of the science education community agrees that pedagogical practices based on the inquiry approach are more effective than traditional ways of teaching and, therefore, using inquiry learning is encouraged in schools. Nevertheless, inquiry learning is not very often used in classrooms by teachers (Rocard et al., 2007). This may be due to different perceived barriers to using the inquiry approach by teachers, such as isolation (Rocard et al., 2007); teachers' own beliefs and values (Anderson, 2002); little support from science curriculum specialists, classroom management problems, the knowledge nature of exams (Harms, 1980); barriers in technical, political and cultural dimensions (Anderson, 1996); and others.

To overcome those obstacles researchers have suggested that teachers need to be supported on different levels. In the Ark of Inquiry project, teachers were trained and provided with different materials about inquiry learning. For designing the training sessions, key roles that a teacher needs to undertake for a successful training session were identified, namely *teacher as learner*, *teacher as thinker* and *teacher as reflective practitioner* (see Irakleous, 2015). In these training sessions, the teachers had the opportunity to (1) experience inquiry learning as their pupils would; (2) receive information on the theoretical and empirical underpinnings of inquiry learning and on possible resources that can be used for inquiry-based teaching and learning (such as the Ark of Inquiry platform); (3) design and implement their own inquiry learning materials or implement existing inquiry learning materials from the Ark of Inquiry platform in their science classes; (4) and to later reflect on these implementations in the presence of their fellow teachers.

In this study about teachers' readiness to use IBL, our aim was to find out whether the barriers for teachers were sufficiently addressed so that teachers would start to use the inquiry approach more in their classroom, or if there are any other additional barriers.

In the context of teacher beliefs, teacher efficacy has proved to be powerfully related to many meaningful educational outcomes such as teachers' persistence, enthusiasm, commitment and instructional behaviour, as well as learner outcomes such as achievement, motivation, and self-efficacy beliefs (Tschannen-Moran, Hoy 2001). In the Ark of Inquiry

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project we aimed to observe teacher efficacy to uncover its influence on the inquiry approach practice and vice versa.

Research objectives

The aims of the study were to evaluate the following:

- What are the characteristics of teachers who use the inquiry approach the most and have positive attitudes towards IBL?
- Do the teacher training sessions have an impact on teachers' sense of efficacy?
- What are the perceived obstacles to using the inquiry approach and can these be addressed through teacher training?
- Will teachers use the inquiry approach more in their classroom after the Ark of Inquiry training programme?

3.2. Study design

Context and procedure

The principles for the teacher training course were developed within the Ark of Inquiry project and acted as guidelines/protocol for all the partners for planning and conducting the training sessions in their countries. The teacher training consisted of three phases (1 – *teachers as learners*, 2 – *teachers as thinkers*, 3 – *teachers as reflective practitioners*). Phases 1 and 2 were tackled in one or two days of teacher training depending on whether the teachers had previous experience in hands-on inquiry activities or not.

At the beginning of the first training day, teachers filled in a questionnaire about teachers' sense of efficacy and their attitudes towards IBL. After the second phase, the teachers had a few months (the exact time varied to some extent between countries and training groups) to practice inquiry learning in their classrooms. This was followed by one more day of teacher training practice (phase 3). At the end of this last training day, teachers were asked to fill in the questionnaires again. In total, the teacher training lasted for two or three days including several months of practice time in between.

Within the training, the teachers had an opportunity to experience inquiry from a learner's viewpoint. Also, different resources for conducting inquiry were introduced, including the Ark of Inquiry web-based platform with a collection of different inquiry activities that teachers can use in their lessons. Given the fixed protocol, which all partners had to follow, the time-on-task across all phases was expected to be the same for all partners. No partner has reported deviations from the protocol, including the time-on-task.

The questionnaires were distributed online (in Google Forms) or on paper. The responses were digitalised if on paper or downloaded in .xls format and sent to the University of Tartu for further analysis.

Sample

From all partners, 10 had the opportunity to collect data about teachers' sense of efficacy and attitudes towards inquiry (see Table 1). The samples are not representative of the countries and the groups are not balanced between countries everyone collected as much data as possible in their context. The teachers' participation in the trainings was voluntary and they were not paid or charged to take part in the trainings. Answering the questionnaire was a part of the training event, although filling in the questionnaires was not obligatory.

Altogether there were 1235 teachers who participated in the trainings. Four hundred and ninety-seven of them also filled in the questionnaires. Pre- and post-test data are available for 228 participants from 7 countries. Most of the participants in the trainings were women (77.9%) and 83.7% of the teachers had at least 6 years of teaching experience. The teachers were from general education schools and taught primary or basic school level. The mean age of the participants was 43. See more information about the participants in Table 1.

Table 1. Description of Study Participants

Country	Overall sample size	Sample size (pre- and post-training data available)	Female proportion (overall sample)	Average age (overall sample)
Belgium	13	3	77%	44
Cyprus	45	43	56%	45
Finland	106	57	79%	42
France	55	0	64%	42
Greece	6	0	50%	38
Hungary	65	0	82%	45
Italy	106	61	94%	50
Netherlands	7	6	57%	28
Turkey	59	40	71%	37
Estonia	35	18	89%	39
TOTAL	**497**	**228**	**78%**	**43**

It is evident from Table 1 that the available data for this study is much smaller than the number of participants in the trainings overall. This has several reasons. Some countries were more focused on other aspects of the project and used different questionnaires. To prevent overwhelming the teachers, these partners decided not to distribute the teacher efficacy and inquiry learning questionnaires. Also, in some cases the lower number of participants in the study has to do with the dropout of teachers from the programme and not being able to fill in the questionnaire at the given time and place (e.g., they had to leave before the end of the session). The reasons for the dropout also stem from the very hectic schedules of the in-service teachers whereby they were not able to attend both sessions. It is also important to note that there were teachers who participated in the second session but were not able to attend the first training session. In three countries, the questionnaire was distributed only once during the training sessions (see Table 1).

Instruments

Teachers' Sense of Efficacy Scale (Tschannen-Moran & Woolfolk Hoy, 2001) was used to measure teachers' sense of efficacy (TE) at the start and at the end of the training. The questionnaire was available in English, Turkish, Greek and French; for all other languages a translation was provided and thus, the teachers were able to rely on their mother tongue. We used the long version of the scale that consists of 24 questions designed to capture the three moderately correlated subscales related to being a teacher: Student Engagement (e.g., getting pupils to believe they can do well in schoolwork; helping pupils value learning), Classroom Management (e.g., controlling disruptive behaviour in the classroom; calming disruptive pupils), and Instructional Strategies (e.g., using a variety of assessment tools; implementing alternative strategies in the classroom). Each subscale consists of 8 questions where teachers indicate on a 9-point scale to what extent they think they can manage in different situations. Both three- and one-factor structures have been found appropriate for use depending on the sample. The 1-factor model has had a better fit for the data in the case of pre-service teachers; otherwise, a 3-factor model has been found appropriate (Tschannen-Moran & Woolfolk Hoy, 2001). Information about the fit of the factor model in the current study can be found in Table 2. On our sample as well, the 3-factor model had a better fit to the data. In addition, we found that the internal consistency of the different subscales was good or very good (Cronbach's alpha ranging from .878 to .909).

Table 2. Model fit of the three-factor structure and one-factor structure of the Teachers' Sense of Efficacy Scale

Model fit indicator	1-factor structure	3-factor structure
Chi-square (df; p)	1313.032 (252; < .001)	1022.014 (249; < .001)
RMSEA	.105	.090
CFI	.805	.858
SRMR	.068	.061

Attitudes towards inquiry learning were measured by one part of a questionnaire that was used in the PRIMAS project (Dorier & Maaß, 2012) to analyse teachers' use and preconception of inquiry and their problems with the implementation of inquiry learning. The part of the questionnaire used in the current project consisted of 23 items where teachers were asked to assess on a scale from 1 to 4 how much they agree to the given statements (see Table 3 for the subscales and questions used in this analysis. Note that not all questions were used, as the questionnaire covered different topics of which not all were the focus of the current study). The authors of the questionnaire have not provided a factor structure for the Use and Preconception subscales of inquiry learning (internal consistency measurements were given with Cronbach's alphas varying from .54 to .60). A three-factor structure was found in the PRIMAS project for the subscales about problems with implementing IBL: System Restrictions, Classroom Management and Resources (see Table 3).

Confirmatory factor analysis was used to confirm the three-factor structure (System Restrictions, Classroom Management and Resources) in the current sample and the fit was relatively good ($\chi^2(41) = 102.6$, $p < .001$; *RMSEA* = .063; *CFI* = .928; *TLI* = .903; *SRMR* = .049). The internal consistency measurements for the inquiry learning questionnaire were generally low. This was expected due to the low number of questions in each subscale. We also calculated mean inter-item correlations for these subscales as suggested for scales with a small number of items by Briggs and Cheek (1986). Briggs and Cheek (1986) recommend that the optimal mean inter-item correlations range from .2-.4. In our sample the mean inter-item correlations vary between .323 and .411 (see Table 3). Subscales with Cronbach's alphas lower than .5 were not used in the study and statistical analysis.

Table 3. Subscales of the PRIMAS questionnaire with internal consistency measurements

Area	Subscale	Items/description	Cr. alpha	Mean inter-item correl.	N of Items	N
Use of IBL	Routine use of IBL	*I already use inquiry learning a great deal.*	-	-	1	380
Preconception of IBL	Knowledge dependence	*Successful inquiry learning requires pupils to have extensive content knowledge.* *Inquiry learning is not effective with lower-achieving pupils.*	.521	.353	2	347
	Motivation	*Inquiry learning is well suited to overcome problems with pupils' motivation.* *Inquiry learning is well*	.582	.411	2	345

		suited to approach pupils' learning problems.				
Problems with implementation	Resources	*I don't have sufficient resources such as computers, laboratory, etc.* *I don't have access to any adequate professional development programs involving IBL.* *I don't have adequate teaching materials.*	.629	.359	3	375
	Classroom management	*I think that group work is difficult to manage.* *I worry about pupils' discipline being more difficult in inquiry learning lessons.* *I don't feel confident with IBL. I worry about my pupils getting lost and frustrated in their learning.*	.692	.360	4	376
	Systemic restrictions	*My pupils have to take assessments that don't reward IBL.* *The number of pupils in my classes is too big for inquiry learning to be effective.* *The curriculum does not encourage IBL.* *There is not enough time in the curriculum.*	.654	.323	4	347

The participants were also asked some questions about their demographics and previous experiences (gender, age, years of teaching experience and subjects taught).

3.3. Results

The results are presented as answers to the research questions.

What are the characteristics of teachers who use the inquiry approach the most and have positive attitudes towards IBL?

First, we found that self-reported use of inquiry learning or attitudes towards inquiry learning are not related to years of teaching experience, which means that teaching experience in itself may not be sufficient for adopting new methods. On the other hand, we found that prior use of inquiry learning was related to attitudes towards IBL. Teachers who had used inquiry learning before compared to the ones who had not (or had very little) perceived fewer restrictions and had more positive attitudes. They believed to a greater extent that inquiry learning is suitable for motivating learners ($t(334) = –2.536$, $p' = .047$) and is not a highly knowledge dependent method ($t(343) = 3.212$, $p' < .001$). They also believed that this method is not more challenging regarding classroom management ($t(375) = 2.729$, $p' = .033$). However, there was no difference between the two groups regarding systemic restrictions and available resources, which indicates that practical experience is not enough to overcome all restrictions. Even though the direction of the described connections is not clear, it indicates that positive attitudes towards inquiry learning go hand in hand with first-hand experiences, emphasising the importance of practical components in trainings.

Secondly, we found that teachers with a higher sense of teacher efficacy have more positive attitudes towards inquiry learning even before the training sessions (see Table 4). The relationship was the strongest related to the attitude concerning classroom management when using IBL. This means that teachers with a higher sense of efficacy are more confident about their classroom management skills and this applies to classroom management in the context of inquiry learning lessons as well. Furthermore, teachers who already use inquiry learning more than others have a higher level of overall teacher efficacy. Tschannen-Moran and Woolfolk Hoy (2001) have also concluded that teachers with a higher sense of teacher efficacy are more open to new ideas and more willing to experiment with new methods.

Table 4. Attitudes towards inquiry learning among teachers with high and low teachers' sense of efficacy

Subscale	Groups*	*N*	*M*	*SD*	*SE*	Cohen's *d*
Knowledge dependence**	low teacher efficacy	178	2.4	.70	.05	.33
	high teacher efficacy	171	2.1	.70	.05	
Motivation**	low teacher efficacy	178	2.9	.58	.04	-.28
	high teacher efficacy	171	3.0	.62	.05	
Resources**	low teacher efficacy	200	2.6	.61	.04	.32
	high teacher efficacy	182	2.4	.66	.05	
Classroom management**	low teacher efficacy	200	2.3	.56	.04	.73

	high teacher efficacy	181	1.9	.51	.04	
Systemic restrictions**	low teacher efficacy	200	2.6	.62	.04	.39
	high teacher efficacy	182	2.4	.67	.05	

* The teachers' sense of efficacy (TE) score was used to create two groups: teachers with high (*M* = 7.4) and low TE (*M* = 6.0). These groups were created based on the median score of 6.75.
** Differences between the groups are significant ($p < .05$).

Do the teacher training sessions have an impact on teachers' sense of efficacy?

When comparing the pre- and post-questionnaire data (N = 228), we found that the teachers' sense of efficacy score for these teachers was 6.69 before the training and 6.82 after the training. Nevertheless, this effect was not statistically significant, as revealed by the Paired Samples T-test, $t(227) = -2.291$, $p' = .069$. The effect is notable only in the Student Engagement subscale, $t(227) = -2.290$, $p' = .016$; no significant difference was found between pre- and post-test measurements of the Classroom Management [$t(227) = -1.399$, $p' = .163$] and Instructional Strategies [$t(227) = -1.896$, $p' = .118$] subscales of teachers' sense of efficacy. On average, Student Engagement was .178 points higher after the training programme (Cohen's *d* value .16).

If we compare the training within our project to other trainings that have been found to be effective (e.g., Ertikanto, Yunarti, & Saputra, 2017; Perez & Furman, 2016), we see that they have some elements in common, such as authentic experience, opportunity for reflection, and opportunity to gain new knowledge (Papaevripidou, Irakleous, & Zacharia, 2017). Within the teachers' sense of efficacy subscales, the only significant effect was in the Student Engagement subscale. This can be explained by the fact that inquiry is supposed to engage pupils more compared to traditional teaching (de Jong, 2006; Pedaste, de Jong, Sarapuu, Piksööt, van Joolingen, Giemza, 2013). It may be that the teachers had positive experiences with IBL, which in turn impacted their general beliefs about how well they can engage pupils. Also, they were now equipped with a new method (in case they had not used inquiry learning before, and also new activities from the Ark of Inquiry platform) for better engaging different pupils.

What are the perceived obstacles for using the inquiry approach and can these be addressed with teacher training?

Teachers rated the systemic restrictions and resource restrictions higher than classroom management or other preconceptions about inquiry learning (see Table 5). Generally, the attitudes towards inquiry learning were more positive after the training sessions (see Table 6). Teachers now saw that there were more resources for inquiry, probably because during the training sessions they saw where they could get and how to create different inquiry activities. After the training, there was a decrease in the view that the classroom is difficult to manage during inquiry learning lessons. Also, teachers now found to a greater extent that inquiry is suitable for motivating learners. The change in these attitudes may be due to greater knowledge gained in the training but also the experiences with inquiry learning in their classroom.

Table 5. Levels of perceived restrictions when implementing IBL.

Attitudes towards IBL	*M* (scale from 1 to 4)	*n*	*SD*
Knowledge dependence	2.3	349	.71
Motivation (scale reversed for comparison)	2.0	349	.61
Resources	2.5	382	.64
Classroom management	2.1	381	.57
Systemic restrictions	2.5	382	.65

However, the attitudes towards knowledge dependence and systemic restrictions did not change. The latter was expected because these attitudes cannot be tackled with trainings alone if they are real. Also, the trainings did not concentrate on the fact that inquiry is actually encouraged by the curricula. It may be that even if it is encouraged by the curricula, it is still not what is evaluated. How to change systemic restrictions, real and perceived, seems to be a challenge we still have to face. Importantly, we also saw that teachers who had a higher sense of efficacy at the beginning of the course saw fewer systemic restrictions. We speculate that teachers with a higher sense of efficacy feel they can overcome the perceived restrictions and manage to incorporate new teaching methods into the frame provided by the school system. If this is the case, addressing and enhancing beliefs about teacher efficacy is a potential way to overcome systemic restrictions.

Table 6. Changes in attitudes towards inquiry learning after the training (only significant changes are shown). A positive value indicates an increase after the training.

Subscale	Cohen's *d*
Inquiry learning is suitable for increasing learner motivation	.277
Resource restrictions	−.359
Classroom restrictions	−.303

Will teachers use the inquiry approach more in their classroom after the Ark of Inquiry training programme?

Teachers reported using inquiry learning more in their classroom after the training sessions, which also indicates a positive effect of the training. This increase is supported by the changes in teacher efficacy and beliefs about IBL, along with various resources for implementing IBL, which means a sustainable effect of the training can be achieved.

Pre-training and post-training use of inquiry learning was assessed through agreement with the statement “I already use inquiry learning a great deal” ranging from 1 to 4. The Wilcoxon Signed Ranks Test revealed that teachers reported using inquiry learning more after the training sessions ($Z = -5.915$, $p < .001$). Overall, 40.8 % of teachers reported stronger agreement with the statement after the training. On the other hand, this result is expected, as within the training teachers were given a task to use inquiry learning with their pupils. Therefore, further studies are needed to see whether the teachers continue to use inquiry learning to a larger extent compared to before the training.

Limitations

The described study also has some limitations. Most importantly, the study relies on self-report data. Further studies should also consider including more objective measures such as observation data. Also, we saw that the reliability estimates (Cronbach’s alphas) for the attitudes towards inquiry learning questionnaire were not very good, probably due to the low number of questions in the subscales, which means that for further use the questionnaire would also need improving. Lastly, the different proportions of participating teachers from different countries and dropout of teachers from the study can also be considered a limitation.

Conclusion

Overall, we conclude that the three-phase training enabled teachers to have positive experiences with using inquiry within a supportive network of peers and teacher educators, as shown in previous research (Papaevripidou, Irakleous, & Zacharia, 2017). Although the training was quite minimalistic, consisting of workshops lasting 2–3 days and an assignment between the workshops, it incorporated significant elements that enabled a change in teachers’ sense of efficacy and attitudes towards IBL.

3.4. Practical relevance

Based on the results of our study we have proposed some practical implications that can be considered by teachers and teacher educators.

Implications for teachers

- Teachers’ sense of efficacy is a prerequisite for being more confident in using new methods. According to Bandura (1997), there are four sources for sense of efficacy: 1) mastery experiences; 2) vicarious experiences (observing others); 3) verbal persuasion (endorsement from others); 4) emotional and psychological states (e.g., negative influence of chronic stress on sense of efficacy). This suggests that hands-on experiences in a supportive environment can indeed positively affect teachers' sense of efficacy, which we also found in our study.

- The positive effect of training sessions on teacher efficacy may also carry over to other areas, as teacher efficacy is related to many different areas of the working life.
- Many of the perceived barriers for using the inquiry approach can be tackled with teacher training. It means that with specific support it may turn out that the barriers may not be as big as originally perceived.

Implications for teacher educators

- Within this training session we did not see an improvement in the attitudes that were related to perceived systemic restrictions when using the inquiry approach. In further trainings this could be addressed more specifically, for example, by discussing the opportunities of using the inquiry approach that go hand in hand with the curriculum.
- Teacher training for encouraging the use of inquiry approach in the classroom can be beneficial for teachers with different amounts of previous experience.
- The teacher training format used in the Ark of Inquiry project had the largest effect on resource and classroom restrictions. Therefore, this kind of training can be recommended if these are the attitudes that need to be addressed.
- The hectic schedule of teachers is something that affects their opportunities for participating in different training sessions. Teacher educators should therefore aim for rather short but effective trainings.
- Effective trainings should provide additional resources for conducting IBL, hands-on activities, opportunities for reflection and support from teacher educators.
- Providing teachers with opportunities to increase their sense of efficacy can have a positive effect on their readiness to adopt different new teaching methods, including IBL.
- When the aim is to encourage teachers to use inquiry learning with the training, there is no need to concentrate on teachers with a specific amount of previous experience as a teacher, because there seems to be no relationship between prior experience as a teacher and using inquiry learning or attitudes towards inquiry learning.

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4. Study 3. Designing a Course for Enhancing Prospective Teachers' Inquiry Competence[3]

4.1. Introduction

Reform documents in science education have underlined the increasing importance of preparing teachers who will play key roles in guiding pupils through cognitive activities centred on inquiry (NRC 2000). Davis et al. (2006) indicated that to design and enact science instruction centred on inquiry, teachers must have a strong understanding of inquiry and good abilities to teach inquiry. Similarly, the National Research Council stressed that "for students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry based methods" (2000: 87).

Despite this persistent call, evidence from the literature revealed that a vast majority of teachers have an unsophisticated understanding of inquiry and do not routinely adopt inquiry learning within their practices due to a number of systemic and other barriers (Crawford 2000, 2007; Davis et al. 2006; Kazempour and Amirshokoohi 2014; Saad and BouJaoude 2012). Consequently, the key to overcome this gap is to invest in teachers' professional development (PD) both at pre- and in-service level. A critical challenge that emerges is to identify the key features that PD programs should entail in order to succeed in changing teachers' epistemic knowledge of the nature of scientific inquiry, helping teachers appreciate the impact of inquiry learning on pupils' scientific literacy, assisting them in understanding how to design inquiry learning in their classrooms (Capps et al. 2012), and consequently influencing the development of their pedagogical content knowledge for scientific inquiry (Davis and Kracjick 2005).

Additionally, it is equally important to identify the role of teachers within such a programme in order to maximize their professional expertise on teaching science through inquiry. Prior research (e.g., Clarke and Hollingsworth 2002, Kazempour and Amirshokoohi 2014) indicates that positioning teachers in the role of active learners rather than information gatherers and letting them experience the same learning journeys that their pupils are expected to follow could be beneficial for their professional development; this role might result in teachers' construction of meaningful knowledge about inquiry and skills for inquiry teaching (Loucks-

[3] Modified and adapted from: Papaevripidou, M., Irakleous, M., & Zacharia, Z. C. (2017). Designing a Course for Enhancing Prospective Teachers' Inquiry Competence. In *Cognitive and Affective Aspects in Science Education Research* (pp. 263-278). Springer, Cham.

Horsley et al. 1998). A second role that is important for teachers to encounter during their participation in a PD program is the role of thinkers of both the learning experiences gained through the hands-on inquiry activities and the underlying design principles of the curriculum materials they engaged with as learners. Theoretical readings, class discussions and other reflective activities may facilitate this role of teachers, as they allow themselves to reflect on their developing understandings, enhance their knowledge about certain aspects of inquiry learning and can shed light on prior established misconceptions about inquiry and science in general (Akerson et al. 2007). Lastly, the capacity to reflect on action that leads to engagement in a process of continuous learning (Schφn 1983) can be a beneficial form of teachers' professional development (Ferraro 2000). Hence, a third role that is considered essential for teachers to follow during a PD program is that of reflective practitioner. This role is facilitated through allowing teachers to implement curriculum materials they developed or received within the context of a PD programme into their own practice, make necessary adjustments to their teaching according to situations occurred at a particular time, collect evidence to evaluate and reflect on the effectiveness of their teaching and bring reports of their field experiences to the course and analyse teaching strategies with their mentors and colleagues.

In this study, we present the structure of a PD programme through which we aimed at impacting pre-service teachers' development of inquiry competence, namely, inquiry skills, views and definitions of inquiry, and pedagogical content knowledge (PCK) for teaching science as inquiry. Our approach draws on the constructs of constructivist learning (Driver et al. 1994) and situated cognition (Brown and Campione 1990). It also builds upon nine critical features of effective inquiry PD suggested by Capps et al. (2012) and follows the recommendations for positioning teachers as learners (Phase 1), thinkers (Phase 2), and reflective practitioners (Phase 3) within the context of a PD program. The development of the curriculum materials incorporated within the course was grounded on the inquiry cycle model suggested by Pedaste et al. (2015).

The research question that we aimed to address was: How did pre-service teachers' (i) development of inquiry skills, (ii) views and definitions of inquiry, and (iii) PCK for teaching science as inquiry change along the course? Specifically, what learning outcomes did pre-service teachers gain during participating in each of the three consecutive phases of the PD program?

4.2. Methodology

The participants were 72 pre-service elementary teachers who attended a science method course in Cyprus, within which the PD program was implemented. During the previous semester, all pre-service teachers attended a content course that made use of the Physics by

Inquiry curriculum (McDermott 1996), whereas none of them taught science during their school practicum.

The PD course, taught by two university instructors and three graduate assistants, was organized into twelve 1.5-hour sessions and split in three phases. During Phase 1, a curriculum titled “Boiling and Peeling Eggs” was implemented, through which the pre-service teachers (groups of four) engaged in multiple inquiry cycles to answer the question “How to make perfect hard boiled eggs that are easy to peel?” Specifically, the teachers as learners defined the problem; identified variables that might affect the boiling and peeling of eggs; formulated investigative questions and hypotheses; designed and performed experiments; collected, analysed and interpreted data; drew conclusions; and presented their findings in posters. During Phase 2, the teachers as thinkers were asked to study the curriculum they previously worked with to identify the phases of inquiry and their interconnections in order to inductively formulate the underpinnings of the inquiry cycle model that guided the design of the curriculum. Next, the inquiry cycle model was introduced, and the teachers compared their perceived frameworks with the original one. Finally, during Phase 3, the teachers were assigned the role of reflective practitioners and were asked to design lesson plans and curriculum materials on a particular topic that they would use to engage an elementary school pupil in inquiry activities. The pupil met with their assigned pre-service teacher for 1 hour after school, one day per week at the pupil’s home. Throughout the meeting with their pupil, the pre-service teachers maintained reflective journals to record their pupil’s inquiry learning progress. Also, pupils created posters, through which they described briefly all the phases of inquiry they went through in the inquiry activities. At the end of the third phase, a science fair was organized at a primary school in Cyprus in collaboration with the pre-service teachers and the school. During the science fair day, the pre-service teachers and their pupils presented their posters to other pupils, pre-service and in-service teachers, scientists/academics and parents. The science fair visitors also engaged in hands-on interactive activities after studying the posters. The interactive activities were organized by the pre-service teachers in order to teach certain aspects of their investigation to visitors. At the end of the course, the pre-service teachers made presentations of their science fair projects, shared their reflections and lessons learned with their peers, and received feedback from the instructors and peers.

We collected multiple forms of data: (a) pre-service teachers’ written definitions of inquiry, as documented in questionnaires administered during the first, the seventh, and the last course meeting; (b) reflective diaries, in which pre-service teachers were asked to document their evolving understanding of inquiry learning (used as a means for capturing their PCK for scientific inquiry); (c) pre- and post-assessment of pre-service teachers’ inquiry skills; (d) science fair project work; and (e) end-of-course individual interviews.

An open coding scheme refined through the use of the constant comparative method (Glaser and Strauss 1967) was followed for answering the research questions. Specifically, pre-service teachers' responses on the various data collection instruments were classified along a three-level inquiry advancement scheme, namely, novice inquiry, basic inquiry, and advanced inquiry. Novice inquiry pertains to pre-service teachers' responses that revealed the presence of naive ideas and misconceptions about inquiry. The second category (basic inquiry) reflected the presence of a limited number of ideas that point to an informed understanding of inquiry combined with instances of naive ideas, whereas the third category (advanced inquiry) evinced the presence of ideas consistent with an informed understanding of inquiry.

4.3. Results

The findings are presented in Table 1 and are discussed in the subsequent three subsections in relation to pre-service teachers' inquiry competence development along the three phases of the PD programme. Representative examples are also included within each subsection as evidence of how we reached these results.

Table 1. Percentage of pre-service teachers' inquiry competence classification across three levels of inquiry (novice, basic, advanced) during each phase of the PD program

Phases of the PD															
	Phase 1: Teachers as learners				Phase 2: Teachers as thinkers			Phase 3: Teachers as reflective practitioners					Final assessment (4 weeks after the end of the course)		
	Pre			Post/Pre			Post/Pre			Post					
	N[1]	B[2]	A[3]	N[1]	B[2]	A[3]	N[1]	B[2]	A[3]	N[1]	B[2]	A[3]	N[1]	B[2]	A[3]
Percentage of pre-service teachers' inquiry competence classification across three levels of inquiry	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Assessment of															
1. Inquiry skills															
1.1. Application of the control of variables skill – data interpretation	5	79	16	0	8	92	x[4]	X	x	0	4	96	0	3	97
1.2. Identification of experimental flaws – revision of experimental design	9	82	9	0	10	90	x	X	x	0	6	94	0	3	97
2. Definition of scientific inquiry	87	13	0	12	58	30	2	26	72	0	13	87	0	4	96
3. PCK for teaching science as inquiry															
3.1. Understanding of the instructional strategies and tools for supporting inquiry	96	4	0	33	67	0	31	56	13	11	12	87	5	7	88
3.2. Knowledge of children's understandings and misunderstandings associated with inquiry	98	2	0	91	9	0	88	12	0	0	31	69	1	8	91
3.3. Knowledge of appropriate curriculum for inquiry	75	25	0	35	62	3	11	25	74	1	11	88	0	4	96

3.4. Knowledge of assessment techniques for inquiry	84	16	0	15	79	6	15	78	7	2	8	90	0	4	96

[1]Novice inquiry: Presence of naive ideas and misconceptions; [2]Basic inquiry: Presence of a limited number of ideas that point to informed understandings about inquiry combined with some instances of naive ideas; [3]Advanced inquiry: Presence of ideas consistent with informed understandings about inquiry; [4]No administration of assessment tasks

Inquiry Skills

The findings revealed that at the beginning of the course, the level of pre-service teachers' acquisition of inquiry skills was moderate (79%, 82% – basic inquiry – see Table 1). With regard to pre-service teachers' identification of experimental flaws skill, the majority of pre-service teachers' responses indicated that they failed to identify all experimental flaws in a given experimental design. We present below a task that was administered to evaluate this specific inquiry skill followed by a representative quote from a teacher's response to document this finding:

> Marina conducted an experiment to test if the material a hammer nail is made of affects its rusting time when placed inside a liquid. She used three test tubes, three different hammer nails and two types of liquids. In the first tube she put an iron hammer nail and water. In the second tube she put a cuprum hammer nail and vinegar. In the third tube, she put a steel hammer nail, vinegar and water. Then, she left them in the kitchen for a week. At the end of the week, she observed that only the iron nail rusted. Therefore, she concluded that water affects the rusting of a metal pin in a better way than the vinegar. Do you agree with Marina's conclusion? Explain the reasoning behind your response. (Adapted from Constantinou et al. 2004)

A representative response that documents the majority of pre-service teachers' failure to identify all experimental flaws and thus their classification in the basic inquiry level is as follows:

> I don't agree with Marina's conclusion, because she should have put the same type of liquid in each tube in order to find out if the type of the material of a hammer nail affects its rusting when placed inside a liquid. (Teacher #14)

The abovementioned response indicates that this particular teacher identified only the type of liquid as the variable that should have been kept constant in the given experimental design and failed to identify other variables (e.g., the volume of the liquid in each tube, the size and material of each tube, etc.) that should have been kept constant. In addition, the teacher did not notice that the conclusion derived from the experimental design is irrelevant to the investigative question being researched (i.e. the investigative question pertains to the type of material of the hammer nail, whereas the conclusion focuses on the type of the liquid).

At the end of Phase 1, pre-service teachers made a significant shift in terms of the development of their inquiry skills (90% and 92% in advanced inquiry level), which was slightly increased by the end of the course (97% in advanced inquiry level, see Table 1). Almost all pre-service teachers were able to identify all experimental flaws in the given experimental design and proposed revisions of the experimental design in order to perform a controlled experiment to answer the investigative question under study. Pre-service teachers' slight inquiry skills improvement by the end of the course might be attributed to the teaching experience they gained during working with their pupils for the science fair project, since they had to help their pupils develop inquiry skills themselves through the curriculum materials and the assessment tasks they developed.

Definition of Scientific Inquiry

At the beginning of the course, all pre-service teachers held uninformed views of inquiry and teaching science as inquiry (87% – novice inquiry – see Table 1). A representative quote with regard to the definition of inquiry learning, provided by a teacher at the beginning of the course and categorized in the cluster of naive inquiry, is as follows:

> Inquiry is a learning situation during which pupils and teacher interact, discuss, and experiment with an appropriate problem and at the end they reach a mutual response. (Teacher #43)

Their definitions of inquiry were continually changed and improved throughout the course, since they progressed from 0% of advanced inquiry at the beginning of the course to 30% at the end of Phase 1, 72% at end of Phase 2, 87% at the end of Phase 3, and 96% at the final assessment which was performed 4 weeks after the end of the course. The following is a representative example of a comprehensive definition of inquiry (clustered as advanced inquiry) provided by teacher #43 at the end of the course:

> Inquiry is a process, similar to the one scientists follow in their daily work, through which a learner engages with a problem and performs several actions for solving the problem. Inquiry involves defining the problem of interest, making some research on getting insight on the concepts that relate to the problem, formulating a question and generating a hypothesis based on the question, designing a controlled experiment to answer the question, collecting and interpreting data, and drawing conclusions in relation to the initial question. The process is not a linear one, since one can follow different paths depending on the type of problem, the conceptualization of the problem, etc., and you can always go back to further investigate your question or formulate and test new research questions. (Teacher #43)

PCK for Teaching Science as Inquiry

Pre-service teachers' PCK for teaching science as inquiry was found to be significantly enhanced only after the end of Phase 3, since at the end of Phases 1 and 2, the majority of pre-service teachers' PCK was clustered as either naive or basic inquiry. For instance, with regard to the aspect "Knowledge of assessment techniques for inquiry" prior to the course, a teacher provided the following response:

> During the first lesson with electric circuits, I would ask pupils to form groups of four and then I would give them a wire, a light bulb and a battery and I would challenge them to find a way to make the bulb lit. Hence, I would be able to observe their reactions, if they are able to collaborate with each other, and with appropriate guidance I would keep notes if they can learn something new by themselves. (Teacher #66)

At the end of the course, pre-service teachers' knowledge of assessment techniques for inquiry was significantly increased (96% – advanced inquiry – see Table 1). An indicative quote from a response by teacher #66 is provided below:

> I would ask pupils to describe what they should do if they wanted to learn whether the sun is essential for plants to grow. In scaffolding their work, I would present 6 different pictures that varied in the type of the plant, the size of the pot, the presence/absence of sun, and the amount of water that is added in each pot, and I would ask them to choose which two they should choose in answering the posed question. (Teacher #66)

Similarly, pre-service teachers' knowledge of appropriate curricula for inquiry was significantly improved. The following extracts from a teacher's lesson plans provided at the beginning and end of the course in a task that sought to evaluate pre-service teachers' knowledge of appropriate curricula for inquiry are particularly revealing:

> The objective of an inquiry-based lesson is to give pupils the opportunity to familiarize themselves with magnets, and especially with their magnetic poles. Initially, the teacher problematizes his pupils, and then pupils experiment and test their hypotheses. The teacher does not provide ready-made responses, but evaluates pupils through appropriate questions. (Teacher #29, before the course, cluster of inquiry: basic)

> The teacher introduces pupils to a problem that relates to why some objects sink and some others float in water. She prompts pupils to pose their initial ideas (these might relate to the identification of variables that might affect the sinking/floating of objects), and helps pupils to formulate hypotheses that they would later test through experiments. Before formulating hypotheses, the pupils formulate investigative questions in the form "Does variable A affect variable B?", and for each question they formulate a hypothesis. Next, the pupils are asked to choose a question and design a controlled experiment (only one variable is altered while the rest are maintained constant) for answering it. During their experiment, they collect data, organize them in a table, and when they have collected enough data, they proceed in interpreting their data in relation to their initial hypothesis and investigative question. The pupils follow the same procedure for answering all investigative questions, and the support from the teacher faints out, as she observes that the pupils are able to transfer the experimental design strategy for investigating the effect of new variables in the sinking/floating of objects. (Teacher #29, at the end of the course, cluster of inquiry: advanced)

Pre-service teachers' knowledge of children's understandings and misunderstandings associated with inquiry has improved by the end of the course. During Phases 1 and 2, the majority of pre-service teachers were classified in the naive inquiry level (see Table 1), and it was at the end of Phase 3 and 4 weeks after the course that they made significant progress to the advanced inquiry level (69% and 91% in advanced inquiry, respectively, see Table 1). For instance, in a task in which pre-service teachers were prompted to refer to the inquiry skills a pupil should master in order to engage in inquiry, a teacher in the beginning of the course stated the following:

> It is essential that pupils should be able to collaborate with each other and follow specific instructions. Also, it is important that pupils are not used to receiving ready-made knowledge, but are able to formulate conclusions themselves. (Teacher # 11, cluster of inquiry: naive)

Based on the abovementioned response, it is obvious that this particular teacher failed to reflect and name some of the inquiry skills that a pupil should have already developed in order to meaningfully engage in inquiry activities. After pre-service teachers' participation in the three consecutive phases of the PD program and specifically after working with an elementary school pupil for the purposes of the science fair project, the majority of pre-service teachers appeared to be able to make statements on the skills that are fostered within an inquiry learning. The following quote from a participant's response documents this assertion:

> A pupil should have mastered several inquiry skills in order to enrol in inquiry activities. These skills are as follows: (i) identification of variables skill; (ii) formulation of investigative questions skill; (iii) control of variables skill; (iv) data interpretation skill; (v) hypothesis generation skill; (vi) hypothesis testing skill. (Teacher # 3, cluster of inquiry: advanced)

As far as pre-service teachers' understanding of the instructional strategies and tools for supporting inquiry is concerned, a similar pattern of improvement was revealed. Specifically, to evaluate this aspect of PCK for inquiry, we administered to the pre-service teachers a set of scenarios that illustrated how different teachers approached the teaching of the same topic with their pupils. The pre-service teachers were prompted to choose which of the scenarios involved instructional strategies and tools for supporting pupils' engagement in inquiry. One of the scenarios was as follows:

> Mr. Lowe is a 3rd grade teacher. One of his eventual objectives is for pupils to learn (at a simple level) about the relationship between form and function. He begins a specific lesson on fish by showing an overhead transparency of a fish, naming several parts, and labelling them as shown. (Adapted from Schuster et al. 2007)

Prior to the course, the majority of pre-service teachers' responses were clustered as naive, since they considered this lesson as inquiry-related and provided arguments like:

> This is a good lesson, because the teacher aims to introduce the terms in a systematic way that the children will need while studying the fish.
> Or,
> I consider this a good lesson, because learning about fish function should start by introducing the names of the fish parts to pupils, and then proceed on studying how these affect the function of the fish.

At the end of the course, pre-service teachers' evaluations of the same lesson scenario appeared to have changed since they considered it as not an inquiry-oriented one. To document their evaluations, they provided responses like the one below:

> This lesson is not appropriate, because it follows a content delivery approach (e.g. the teacher provides the names of parts of the fish to the children) and there is no evidence to show that the teacher aims to prompt pupils to develop questions and hypotheses of how and why each part of the fish affects its function.

This finding can also be attributed to the rich teaching and learning experience they received during their efforts to engage their pupils with inquiry activities and scaffold the development of their inquiry skills and understandings about critical aspects of inquiry (Phase 3 of the PD program).

4.4. Practical relevance

The purpose of this study was to investigate the effect of a PD programme on pre-service teachers' development of inquiry competence. The findings demonstrate significant shifts of pre-service teachers from naive to advanced inquiry in all three aspects of their inquiry competence (inquiry skills, definitions of inquiry, and PCK for teaching science as inquiry). It appears that our approach, particularly the features of the course and the three distinct participatory roles that pre-service teachers were assigned to during their engagement in the three consecutive phases of the PD programme, was particularly effective.

From a practical viewpoint, the findings of the study are of interest to teacher educators who are willing to design and implement PD programmes that aim to prepare pre-service teachers how to design and teach science as inquiry. Specifically, the findings shed light on how the nine critical features of effective inquiry derived from Capps et al. (2012) (*total time, extended support, providing teachers with authentic experiences, coherency with standards, development of lessons, modelling inquiry, reflection, transference, and content knowledge*) can be addressed in the design and implementation of PD courses in order to enhance both pre-service teachers' teaching and learning competence about inquiry learning.

Below, we suggest some directions for teacher educators on how to incorporate these features into the design and development of a PD program. First, as far as the *total time* feature is concerned, PD programmes should run for an adequate length of time to help teachers deconstruct their understandings about learning and teaching through inquiry (Capps et al. 2012), and eventually modify their teaching practices (Supovitz and Turner 2000).

Second, the element of "*extended support for teachers*" is considered as a vital feature of a successful training programme and thus it is suggested to be considered when designing and implementing such programmes. Teacher educators could arrange classroom visits or meetings where teachers physically get together. Furthermore, they could provide remote support sessions with the use of technological tools (e.g., via social media, emails, etc.). In these sessions, teachers would have the opportunity to report any problems that they may have in their teaching, receive feedback about their inquiry-based instruction, as well as suggestions for improvement. Thus, they would be able to revise their teaching practices accordingly. This is in agreement with the existing literature, which postulates that the provision of support influences teachers' willingness to change their teaching practices (Simon et al. 2011).

The third feature that teacher educators should take into account while designing a professional development programme is the engagement in *authentic experiences* similar to those that scientists engage with. For example, teacher educators could provide teachers with the opportunity to work in a laboratory or conduct a field study with the aid of scientists carrying out their own investigation. Teachers who receive authentic inquiry experiences – similar to those they are supposed to implement at a later stage in their classroom – are expected to be able to better translate their learning experiences into meaningful practices for their pupils, better communicate and relate concepts to their pupils, and have a higher impact on enhancing pupils' interest and achievement in science (Dubner et al. 2001).

Another feature introduced by Capps et al. (2012) that should be taken into consideration is the *coherence* of the aims and content of the course with the national curriculum. Thus, the compatibility and coherence is expected to facilitate and support teachers' teaching practice. This conjecture is in line with what Grant et al. (as cited in Garet et al. 2001: 927) claimed; namely, if the sources used for teachers' training "…provide a coherent set of goals, they can facilitate teachers' efforts to improve teaching practice, but if they conflict they may create tensions that impede teacher efforts to develop their teaching in a consistent direction."

In addition, a different feature that teacher educators might bear in mind is the discussions on how teachers can *transfer experiences* or materials in their own field of practice. By letting teachers discuss the ways they can apply the novel knowledge, skills and supporting materials acquired during the training period, they will probably integrate the inquiry approach in their classroom.

Lastly, a programme should not only focus on engaging teachers in inquiry activities but also on helping them develop specific *content knowledge*, including understanding of certain aspects of the nature of science, the nature of scientific inquiry, and the science concepts. This is in accordance with Capps et al. (2012), who claimed that if teachers' development of adequate content knowledge is neglected within their training, "they will likely be uncomfortable with the material they teach and have difficulties when they attempt to teach the material" (Capps et al. 2012: 302).

Another important lesson learned that derives from this study and can be included as a recommendation to teacher educators relates to the roles that teachers take during their training in order to maximize and grant their productive participation in inquiry oriented training programmes. The first role that is important for teachers to encounter during their participation in a professional development programme is that of *learners*. Previous studies (e.g., Loucks- Horsley et al. 1998) have emphasized that professional development programmes should model inquiry learning in ways that allow teachers to experience inquiry in an active setting as learners rather than being presented information in a typical lecture format. In this way, they have a better understanding of inquiry and a better sense of how their pupils might experience inquiry, and increase their confidence for guiding their pupils as they are involved in the inquiry activities. According to Radford (1998), "teachers are most likely to internalize science concepts and teaching methodologies when both their hands and minds are engaged in the process". Giving to teachers the role of learners at the beginning of their professional learning is essential, because teachers must first experience the methods and activities that we expect them to use in their classrooms in a supportive environment that allows them time to reflect on their experiences.

In addition, it is of pivotal importance to give teachers the opportunity to act as *thinkers*. Discussions on their experiences acquired throughout the previous role allow teachers to reflect on their developing understandings, improve their knowledge about inquiry, and eliminate many misconceptions about inquiry (Akerson et al. 2007). Specifically, the identification of the phases of inquiry model by the teachers will enable them to think of possible ways of how they might adapt this inquiry model to their classroom teaching and consequently, gain confidence to teach through inquiry (Seraphin et al. 2013). Thus, this role is a transitional stage between the role of thinkers and implementers.

The third role that is meaningful for teachers' professional learning is "teachers as *reflective practitioners"*. Providing teachers with opportunities for reflecting on their teaching practice constitutes a main component of their training. The reflection process serves as a debriefing time for the participants, allowing them to record personal experiences, assess their practices, share any learning difficulties / problems / obstacles that they encountered during their teaching and examples of unsuccessful and or successful lessons learned during their implementations. By analysing what “works” and what “does not work” in their classroom, they explore their own practices which in turn will lead to changes and improvements in their own teaching (Freese 1999).

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5. Study 4. Inquiry Learning as a Pedagogical Framework for Promoting Responsible Research and Innovation as a Way of Making Sense of Science in and for Society[4]

5.1. Introduction

The notion of Responsible Research and Innovation (hereafter *RRI*) was originally introduced in different EU policy documents aiming at re-imagining the way in which research can contribute to society. In a nutshell, what the notion of RRI aspires to contribute to is the promotion of a culture of responsibility and a way to conduct inquiry that is participative and inclusive (Sutcliffe, 2011; De Vocht and colleagues, 2017). For science education the introduction of Responsible Research and Innovation is indeed a challenge. In general terms, RRI invites educators and teachers to form future citizens able to collectively *take responsibility* for science and scientific inquiry in and for society. This brings our attention to one crucial aspect: the meaning that responsibility has or may have in the specific context of science education. In our view, it should not be seen as a mere "ethical add-on" devoted to discussing the ethical implications of scientific inquiry but as a term that needs to be investigated in connection to exhibiting responsibility for the inquiry process.

In order to investigate what that actually means, we decided to focus on the practice of inquiry learning in the class. The reason behind this decision is that during inquiry activities pupils are given the opportunity to have a "taste" [5] of what scientific inquiry is or could be. They can pose and articulate research questions, elaborate conjectures and hypotheses, design and perform experiments, draw conclusions from the data collected, discuss and communicate their findings, etc. These represent – at least in theory – all moments in which pupils may be or may not be given responsibility in and for the inquiry and thus the opportunity to clarify its meaning.

Establishing the connection between the practice of inquiry learning, on the one hand, and RRI, on the other, allows us to specify the main research question that led the way in the present study: What is the meaning that the term *responsibility* actually acquires during an inquiry-based lesson?

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[4] Modified and adapted from: Bardone, E., Burget, M., Saage, K, Taaler, M. (2017), Making sense of RRI in science education through inquiry-based learning. Examples from the field, *Science Education International, 28*(4), 293-304.

[5] It is worth noting that the analogy between inquiry-based learning and scientific inquiry has been criticized. See, for example: Hodson, 1998; Hodson and Wong, 2014.

This main research question can be specified further into two:

1. How do teachers include pupils in the different inquiry phases?
2. What kind of decisions are pupils given responsibility for during the different inquiry phases?

The text is structured as follows. After describing the research design that we followed during the study, we will dedicate ample space for presenting our ethnographic findings, trying to retain, as much as possible, the level of details and nuances as they appeared in the class. This will be the empirical basis for a discussion in the third section that brings our observations in the classes to a higher level of abstraction hopefully clarifying the ambiguity that the term *responsibility* may happen to have and point to a few practical implications.

5.2. The design of the study

The study consisted of pre-fieldwork interviews, observations in the field and post-interviews. Figure 1 provides a graphical representation of the overall design as well as the timeline.

The participants comprised seven science teachers in the Estonian general education system who taught grades 2–12. We decided not to focus on a specific age group of pupils. As the present study is exploratory, we thought that trying to cover the all spectrum would help us see variations of the phenomenon under investigation.

Figure 1. Timeline of the study

We held the pre-fieldwork interviews with 14 teachers. Seven teachers agreed to participate from the second phase of the study onwards. The seven teachers were observed at least 3 times.

The pre-interviews allowed an in-depth look at what the teachers meant by scientific inquiry and inquiry learning, as well as their familiarity with RRI. That provided the background for the observations that followed. The questions we asked in the pre-interview were, e.g., “How do you think inquiry learning can be compared with the way in which scientists conduct their own inquiries?”, “How do you usually bring up ethical/social issues in case an inquiry activity gives you the opportunity to do so?” The interviews were semi-structured and took place from March 2016 to May 2016. Only in one case the pre-fieldwork interview, observations in the class and post-fieldwork interview took place from March 2017 to May 2017.

Observations in the class were conducted by a team of at least two observers. A total of 23 lessons and 19 inquiries were observed. Overall, the workgroup was composed by 4 researchers.

The post-fieldwork interviews with the seven teachers took place after the observations from May 2017 to June 2017. The post-fieldwork interviews were semi-structured and helped, for example, to clarify possible points of confusion emerged during the observations in the class. In addition, we asked the teachers to tell us about their responsibilities during inquiry-based lessons and what are those that pupils should have.

5.3. Results

In general, the twenty-three cases observed sit *variably* along a continuum whose two ends represent two approaches to inquiry, which stand in stark contrast with each other. We call the first type "the scripted approach". This is the approach in which the teacher follows a sort of script, which she/he has in mind before hand, and during the class she/he acts so as not to deviate much from it. Generally, the process holds an instrumental value in arriving at the *right* answer or result. Which means that the inquiry serves the main purpose of *demonstrating* that something is the case, rather than allowing pupils to freely explore.

The second approach is radically different from that, as it sees inquiry as essential an open-ended activity. Pupils are given the maximum level of freedom to decide what to do and how to do it during the different inquiry phases. The teacher recedes into the background, letting pupils take responsibility for and full ownership of what to do.

In order to try to retain as much as possible the kind of richness characterizing the practice of inquiry in the class, we decided to describe per each inquiry phase three different paradigmatic cases: one case that is closer to the scripted approach, one that is closer to the open one, and a third case that sits somehow in the middle. The main purpose of that is to show the variations and differences that have occurred in the different inquiry phases that we have observed (See the table in Annex 2 for a summary).

In the presentation of the cases, we will focus specifically on the inquiry phases, because we have observed that virtually in all 23 cases the inquiries did not substantially deviate from the inquiry cycle model illustrated by Pedaste and colleagues (2015). Specifically, we have identified and described what happened in four phases: Orientation, Conceptualization, Investigation, and Conclusion. In presenting the examples from the field we will follow the same structure. It is worth noting, though, that in the model there is a fifth phase named

Discussion, which, according to Pedaste and colleagues, spreads across the entire inquiry cycle. What we have observed is that discussions took place throughout the inquiry process and they were present in each phase. Therefore, in order to avoid being redundant, we decided to leave this phase out and concentrate on the remaining ones.

The Orientation phase

Example 1

The first example that we present is closer to what we called the scripted approach to inquiry. The inquiry in question was carried out by ninth-graders in collaboration with two biology teachers, Laila and Urmas[6], who decided to join forces for that occasion. The inquiry was aimed at investigating the effect of physical exercise on one's heart rate, and it started with one of the teachers showing a clip that was projected onto the screen situated in the classroom. The short clip, provided a visual model of how the human cardiovascular system functions. The clip gave the teachers the chance to provide a short recapitulation of the main components of the heart, which was a topic that had been treated during a previous lesson. The clip also offered an introduction to the actual topic of the inquiry, for which the two teachers took full responsibility for. They also took responsibility for providing the kind of background information required to conduct the actual inquiry. No real discussion followed the projection of the clip. Since each and every pupil had a tablet at their disposal, the Orientation phase ended with the teachers asking the pupils to download the template from the repository for use during the inquiry. The template contained all the prescribed inquiry phases the pupils had to go through during the lesson, and so it helped them be on track.

Example 2

A different pattern was shown by Liina – a class teacher of second grade pupils. The aim of the inquiry was to measure the temperature of one's own body as well as that of different spots in and outside the classroom, e.g., in the schoolyard, at the window, next to the radiators, etc. The pattern that we observed sits somehow in between a scripted approach and a more open one. Like in the previous case, it was the teacher who decided *what* to inquire into, and she took the responsibility for introducing the topic. However, unlike the previous case, the kind of background information needed to carry out the inquiry was brought out via a discussion, which left room for pupils to have their own say. Specifically, as the teacher had previously asked the pupils to bring their own thermometer, she engaged the pupils in a discussion concerning what kind of thermometer the pupils had to use to measure the temperature in different places. While it was her leading the way, the pupils were fully engaged in discussing the possible options as well as trying to reach an agreement. As part of the Orientation phase, the teacher showed the pupils how to write down the temperature values. Again, the teacher led the process here, but instead of providing the answers straightforwardly or expecting the right answer from the pupils, she invited them all to give their own opinion, which the pupils then tried to explicate. Regarding

[6] In order to guarantee the privacy of the teachers involved in the study the names that are going to appear are pseudonyms.

this specific example, in the post-fieldwork interview teacher Liina told us that she often asks pupils to bring their own equipment, because she feels that in this way they feel more included.

As far as the Orientation phase is concerned, we did not observe any example in which the pupils were free to decide on the topic for their own inquiry. However, we present a case that is somehow closer than the others to the “open” approach.

Example 3

This case was different from all others, first of all, because the inquiry activity spread across three 45-minute lessons or meetings on three consecutive days. Secondly, as the lessons were part of an elective course that could be freely chosen by gymnasium pupils.

The general theme of the inquiry was chosen and then presented by the teacher. It concerned two main areas of interest in psychology, namely, optical illusion and body language. The presentation delivered by the teacher consisted of a few slides that were shown to the pupils and, overall, it lasted roughly 15 minutes.

During the presentation, the teacher showed the pupils particular examples of optical illusions and body language, which served the main function of exemplifying possible topics rather than imposing a specific one. That was because the task to decide which topic to select and the specific problem to address was assigned to pupils, who then carried out the rest of the inquiry activity in groups.

In the course of the first part of the lesson, the teacher informed the pupils about the plan for the next two days. The pupils had to work in groups to design and conduct an experiment for the second day and present the results to the class on the third. He explicitly stated that pupils could freely choose a specific topic for the inquiry and use whatever they wanted – including their own imagination. Before wrapping up, he also added that in case they started panicking, they could do the work together with him.

In the rest of the lesson the teacher receded into the background and the pupils formed groups according to their own preference and continued the inquiry activity. This chiefly involved the selection of the particular topic and outlining what to do in the next phases. What virtually all groups did was to search for information on the Web, using either their mobile devices or a laptop. In the cases observed that meant looking for information concerning different optical illusions and the major online tool deployed was Google image. While the searching was usually performed by one member of the group, the results were shared and discussed with other pupils. What concerns time management, pupils were allowed to work outside of the class and, more in general, to manage time their own way. In some cases, pupils left before the end of the class, while in others, they stayed in the class a bit longer to finish off what they had started. Figure 2 illustrates the variations occurred in the three cases and recapitulates the main differences.

	Example 1	Example 2	Example 3
Background information on the topic	Delivered by the teacher directly	Delivered through a discussion initiated by the teacher	Searched for by the students divided into groups without direct teacher's assistance
Specific problem to address	Identified by the teacher beforehand	Identified by a discussion initiated by the teacher	Identified by the students divided into groups without direct teacher's assistance

scripted → open

Figure 2. Variations during the Orientation phase

The Conceptualization phase

Example 1

In the previous section we mentioned the inquiry concerning the cardiovascular system conducted together by teachers Laila and Urmas. The Conceptualization phase, too, offers an example of a rather scripted type of approach. Similarly to the Orientation phase, Laila and Urmas firmly led the process. So, after the topic was introduced by showing pupils a clip describing the main components of the heart, the teachers briefly described what they held in stock and then asked the pupils to guess their heart rate at rest and right after having a run through the entire school building. Pupils were supposed to write down their "hypothesis", which in this specific case was a guess to a specific question – their heart rate before and after the tour around the school. Pupils were not involved in making any meaningful decisions concerning the way in which to frame and/or conceptualize the main topic under investigation. The teacher took the responsibility for narrowing down the topic without engaging the pupils in the process. Here again the post-fieldwork interview helps provide context. Teacher Urmas expressed his concern in relation to the fact that eventually, pupils should provide the kind of answer that he expects. He also added that if every pupil came up with his/her own research question, the class would become simply unmanageable.

Example 2

A different example comes from another case, which is more open and less scripted. This was the case of teacher Hanna and her seventh-grade pupils. The inquiry that they conducted was about reflex arc and reaction time. The topic was introduced by the teacher in the Orientation phase. During this phase she made explicit several of the connections that the topic has with problems that pupils encounter in their everyday life. Chiefly, she talked about how alcohol or fatigue may have detrimental effects on one's reaction time and how bad that is in case a person is driving. While this part was led by the teacher, who, indeed, was making an effort to make the subject appealing to the pupils, in the Conceptualization phase she involved the pupils directly in formulating the research question. While she herself told the pupils that reaction time can be faster or slower, she encouraged them to think of a research question based on the knowledge that they had previously acquired. To scaffold the process, she went to the blackboard, inviting the pupils to suggest a question that would follow the formula "how something influences something else". With the help of the teacher, the whole class eventually came up with a research question concerning how distracting factors influence our reaction time, which the teacher wrote down on the blackboard. Although the teacher gave several hints as to how to formulate the research question, the pupils were involved in the process of conceptualizing the main object of investigation, which, unlike the previous case, involved something more than having a guess as to what is going to happen. She was also open to the suggestions coming from the pupils and ready to include those as part of a brainstorming process. Interestingly, commenting on this specific case, teacher Hanna remarked in the post-fieldwork interview that her role is "to monitor and guide the process".

Example 3

The third case, which is the one closer to the "open" type, again concerned teacher Leo and the pupils who participated in his elective course. We have previously described that in the Orientation phase the teacher took the lead, introducing a number of broad topics for the actual inquiry, namely, optical illusions and body language. Once he introduced the topic in the Orientation phase, pupils were left on their own to decide on the specific topic to address and how to conceptualize it, which was the main task for the Conceptualization phase. While the pupils were aware of how the three lessons were organized, the teacher did not pace them up in any way. The pupils knew that the next day they had to perform an experiment before the class, which implies that they had to come up with a hypothesis or research question that they could actually investigate. As we have mentioned above, pupils worked on the inquiry across three consecutive days. Since we only observed the pupils in the class, we cannot say much about what was going on outside of it. However, during the presentation of their inquiry all groups introduced their work by specifying the research question and/or, in some cases, one or more hypotheses that were tested during the Investigation phase. Figure 3 illustrates the variations occurred in the three cases presented and recapitulates the main differences.

	Example 1	Example 2	Example 3
Formulation of the research question or hypothesis	Provided by the teacher	Formulated through a discussion led by the teacher	Autonomously formulated by the students divided into groups

scripted → open

Figure 3. Variations during the Conceptualization phase

The Investigation phase

Overall, the Investigation phase was a central moment in the whole inquiry process, and that is why we are going to devote ample space here to it. The first thing to mention is that the Investigation phase was not a single block, though, but composed of three fundamental sub-phases: the design of the experiment, the experimentation, and the compilation and sharing of the results. In the presentation of what we have observed in the classes we will follow this division.

Example 1

Design of the experiment

The inquiry – carried out by seventh grade pupils in collaboration with teacher Ülle – aimed at the calculation of the volume of a cylinder. This was supposed to be done by immersing a cylinder in a small bowl containing water to measure how much the water level consequently rose. Before the experimentation sub-phase, the teacher went through the instructions provided in the worksheet that all pupils received at the beginning of the lesson. The teacher showed, one by one, every single piece of the equipment that the pupils were supposed to use, namely, a black cylinder not taller than 5cm and the bowl to fill with water. She also pointed to the sink right next to her desk where pupils would get water. In addition to that she gave the pupils a practical demonstration as to how to measure the diameter of the cylinder. She took extra care that pupils would write down the correct units next to the numbers.

Experimentation

During the actual experimentation pupils made decisions about the implementation of the plan previously devised by the teacher. The decisions concerned the execution of the steps required. Those included, for instance, measuring the diameter of the cylinder and pouring water into the bowl. While the teacher provided a demonstration of measuring the diameter, pupils had to skilfully put to use a ruler and set square. To fill the bowl with water, pupils – often in pairs – walked to the sink next to the teacher's desk and measured the amount of water poured in the bowl, making sure that it was the right amount. Some other decisions concerned teamwork and division of labour, e.g., who would pour water and who would measure its level in the bowl. The teacher left pupils freedom to decide whether to work in a group or not, and the pupils also decided how to assort themselves in the group. Only one pupil opted for carrying out the task alone.

Compilation and sharing of the results

After the experimentation sub-phase, the pupils were simply asked to write the answer to the question contained in the worksheet that the teacher distributed and went through at the beginning of the lesson. That was the last part of the experimentation phase. No further discussions or reflections followed.

Example 2

While the first case approximates, to a large extent, what we have called a "scripted" approach, we are now presenting a second case, which moves closer to the "open" type. The second case regarded another inquiry conducted by teacher Liina and her second-graders, whom we have already mentioned. The inquiry consisted in burying different items in the ground in September (right at the beginning of the school year) to see in May how much the different materials have degraded in the soil. Overall, the activity had the same structure as any inquiry. The Investigation phase followed the Orientation and Conceptualization phases and was composed of the three sub-phases that we mentioned before.

Design of the experiment

The teacher asked the pupils to make key decisions along the process. First, she asked the pupils to bring from home items to bury in the ground. She also assisted them in what followed. After the pupils were shown the items to bury, the teacher asked before the entire class where they wanted to dig the hole. The school – located in the centre of a small village – had a big garden that extended for a few hundred meters from the school building. So, the location for the hole was not entirely obvious. A discussion followed. Pupils agreed that the place should be where the ground is soft and where it would be unlikely that people would tramp on it.

Unlike in the previous case, matters concerning the "design" elements were not all settled at the beginning of the Investigation phase. So, after the hole was dug and the items buried, the teacher asked how to remember the exact location of the hole in May. This was another important thing to decide upon. Indeed, if the pupils could not locate the exact place, they would either waste a lot of time before digging out the items or the entire inquiry could be jeopardized. Here again a discussion followed. The first idea was to draw a map of the place.

Since the hole was located a few meters from a metal post, some suggested wrapping an orange band around it. Some others counted the steps from the post to the hole. Interestingly, this last proposal triggered further questions, as then the pupils had to decide how to measure the steps.

Experimentation

Apart from these design elements, as we called them, the central moment of the Investigation was, as we anticipated, the digging of the hole. Again, unlike in the previous case, pupils were not given instructions as to how to dig the hole. Conversely, the teacher involved the pupils in taking active part in what we may call "micro-inquiries", which consisted in deciding upon a number of issues *as they arose*. Similarly to the case of deciding how to mark the location of the hole, which prompted further questions concerning how to measure the steps, the pupils had to make a number of decisions that were only partly initiated by the teacher. They had to decide the exact spot where to start excavating, how wide and deep the hole had to be, and those who were involved in digging the hole – mostly boys – had to figure out how to use the spade effectively. Not all pupils were actually involved in the excavation. Some were sent by the teacher to collect pebbles, which were later put on the top once the hole had been filled again. Interestingly, as the experimentation sub-phase drew to an end, the teacher told the pupils that she would be very busy in May and that they would therefore have to remind her of their inquiry.

Compilation and sharing of the results

The last part of the Investigation phase – the one concerning the results – took place in late May. The items were dug out and we observed the same repeating pattern with the teacher letting the pupils lead the way, occasionally asking questions. It turned out that finding the exact location was not easy. Interestingly, even the teacher was not so sure where the hole was, and the surprise of spotting the first item was indeed authentic for all the subjects involved. After the excavation the inquiry continued outside, where the Investigation phase drew to an end and the Conclusion phase began.

Example 3

We now come to the third and last example, which is even closer to what we have termed the "open" type. We have already encountered teacher Leo and his pupils. As mentioned above, this was an elective biology course that tenth, eleventh and twelfth grade pupils were free to choose. In this case, too, the Investigation phase was characterized by three moments or sub-phases.

Design of the experiment

Pupils had the chance to make all the necessary decisions during the whole investigation. This involved, first of all, thinking of an experiment that would address the main research question or hypothesis. It is hard in this case to separate the two moments, as the actual problem to address and the discussion of the design of the experiment went hand in hand.

More in general, during this sub-phase, the pupils decided how to experimentally approach the specific topic that they chose independently. Interestingly, the groups addressed different issues within the larger topic introduced. They also had to decide how to collect the data, which meant they had to opt for a tool to use for that. So, for example, a group – conducting an inquiry on reasoning under time pressure – decided to use *Kahoot!*, a learning application allowing multiple-choice quizzes, which all the pupils seemed to be familiar with.

In another case, the experimenter asked the subjects to follow his verbal instructions to perform certain gestures, such as touch their shoulders, nose, etc., while performing the gestures himself before them at the same time. Only in the last case the gesture he performed did not match with the verbal instruction given to the subjects. The experiment was supposed to investigate whether the subjects would still follow the verbal instruction or not. For collecting the data, the experimenter decided to video-record the whole experiment, asking for the teacher's help, as they found that to be the only way to investigate the research question.

Experimentation

We observed during this sub-phase that pupils had already decided how to divide all the tasks. For example, one group asked pupils to guess how many grapes a little jar contained. In order to do so, they decided to perform the experiment in the corridor, calling the subjects – including the teacher – one by one. One group member stayed in the classroom, handing out and then collecting the pieces of paper on which the subjects had to write their guesses. With the exception of one group, the experiments were performed during the second lesson. The fellow classmates were the subjects of the experiments. It is worth noting here that the teacher stepped down from his usual role and took part in the experiments just like any other pupil. On one occasion, he temporarily joined the experimenters, helping them with video-recording, because he was explicitly asked to do so. Otherwise, he generally looked amused by what the pupils came up with and occasionally asked questions triggered by curiosity rather than by his role as an assessor.

Compilation and sharing of the results

The results were shared by each group before the entire class in the third lesson. Every group collaboratively prepared a few slides in which they described in detail the kind of inquiry that they conducted – the research question, design of the experiment, independent variables that were chosen, etc. All inquiries were quantitative and the graphs displaying the data were commented on. During the presentations the teacher stood at the back of the room and listened attentively. He commented on each and every presentation, focusing mostly on technical aspects, such as the size of the sample (which in all cases was too small to allow generalizations) or the way in which the statistical analysis was done and the data visually presented. In general, he did not suggest any alternative way of doing the experiments, acting very much like a good reviewer – providing specific feedback on what the pupils did and showed.

	Example 1	Example 2	Example 3
Design of the experiment	Provided by the teacher through the worksheet	Articulated in a discussion led by the teacher, in which students gave their own contribution	Articulated autonomously by the students divided into groups
Experimentation	Performed by the students while the teacher checked that everything was done correctly	Delivered through a discussion initiated by the teacher	Performed by the students divided into groups
Compilation of the results	Prompted by questions provided in the worksheet	Prompted by a discussion led by the teacher	Performed by the students in the class before the teacher

scripted ⟶ open

Figure 4. Variations during the Investigation phase

The Conclusion phase

Example 1

Here again the first example concerns a more scripted type. The inquiry in question was performed by Laila, whom we have already met, and her class of seventh grade pupils. The Orientation and Conceptualization phases were part of a homework in which pupils were asked to design an experimental situation where CO_2 would form as a result of a chemical reaction. In the 45-minute class the task was to perform, in groups, the experiment that pupils had prepared at home. All the groups opted for burning a match to demonstrate the formation of CO_2. Since the main aim of the inquiry was merely demonstrative, that is, to provide a demonstration of a specific effect, pupils were supposed to simply write down the result of the demonstration and were not asked to analyse what had happened during the experimentation any further. When the Conclusion phase started, the teacher asked each group *why* the match had gone out and how the pupils knew that CO_2 had formed. Interestingly, in those cases in which the pupils did not get the expected result – that is, the one that the teacher expected – she simply told them that something practical went wrong during the experimentation. In the last part of the Conclusion phase the teacher invited the pupils to explain the reason why CO_2 was formed by looking for the answer in their handbook.

Example 2

The second example comes from the inquiry lesson in which Liina and her second grade pupils investigated how fast different items deteriorated when buried in the ground. As mentioned already, the first three phases took place right at the beginning of the school year, when a number of items were buried. The Conclusion phase (and part of the Investigation phase) took place in a lesson in May when the items were excavated. In the first part of the Conclusion phase, the pupils extracted the items and it turned out that paper and cardboard were the most degraded materials. While the teacher was leading the discussion as to why it was so, the pupils actively participated in formulating a possible explanation. For example, an explanation that the pupils provided was that paper and cardboard were "made of nature". The way in which the teacher led the discussion was not meant to result in one single answer. Conversely, she waited for each and every pupil's opinion, valuing their effort to provide an answer rather than expecting the right one. Interestingly and unlike in other cases, in the Conclusion phase the teacher engaged the pupils in a final reflection concerning what they had done, asking them what they enjoyed the most during the whole inquiry process that spanned across several months. The pupils took this last task very seriously and appeared very engaged in telling the teacher what they had liked. Here again the teacher welcomed all opinions, giving the clear message that there was no right answer and anyone could share his/her own view.

Like in the case of the Orientation phase, we did not observe any example that was more open than the one described. It must be noted that on many occasions the Conclusion phase was somehow shortened by the teacher simply because they ran out of time. It might be of interest, though, how the Conclusion phase of the inquiry that involved teacher Leo and his pupils came to an end: as mentioned before, the Investigation part ended with each group presenting the results of their inquiry. The teacher performed the role of a reviewer, providing specific feedback, mostly on the design of the experiment. After all groups had presented their results, the work done by the pupils provided the chance for the teacher to literally walk them through the key elements of scientific inquiry as well as provide a recapitulation of what the pupils had been involved in during the previous two days. He took care of naming and describing the elements so that the pupils could better understand why they did what they did. Those elements were the research problem and background information in the first phase; the hypothesis in the second; the experiment in the third; analysis and presentation in the fourth; and drawing the conclusions in the fifth and last part. He stressed, as he had done during the pupils' presentations, the crucial importance of sampling and the way in which results can be visually presented. The pupils listened attentively and one took a photo of the schema that the teacher delineated on the blackboard. However, no discussion followed. Figure 5 illustrates the variations occurred in the three cases presented and recapitulates the main differences.

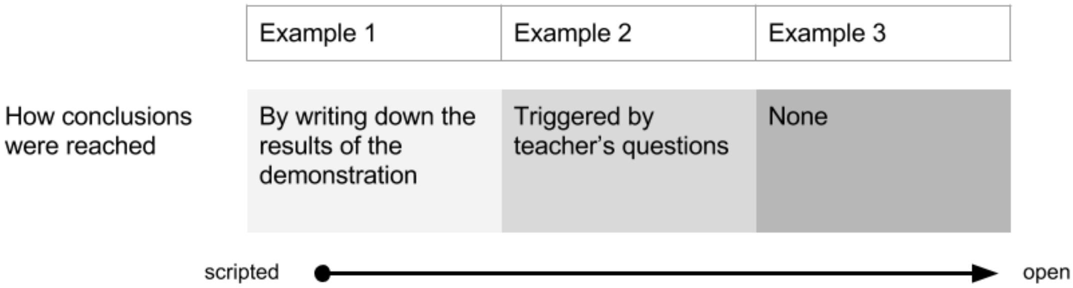

Figure 5. Variations during the Conceptualization phase

5.4. Discussion of the results and their practical relevance

As we mentioned above, the main purpose of the study is to investigate the meaning that the term responsibility may acquire in inquiry-based lessons. Overall, what we have observed is that the meaning of the term responsibility depended very much on the kind of approach to inquiry that the teacher adopted in the lesson, which, in turn, affected the way in which the teacher included pupils in the inquiry process *and* consequently the types of decision that pupils were given responsibility for. Figure 6 schematically represents all that.

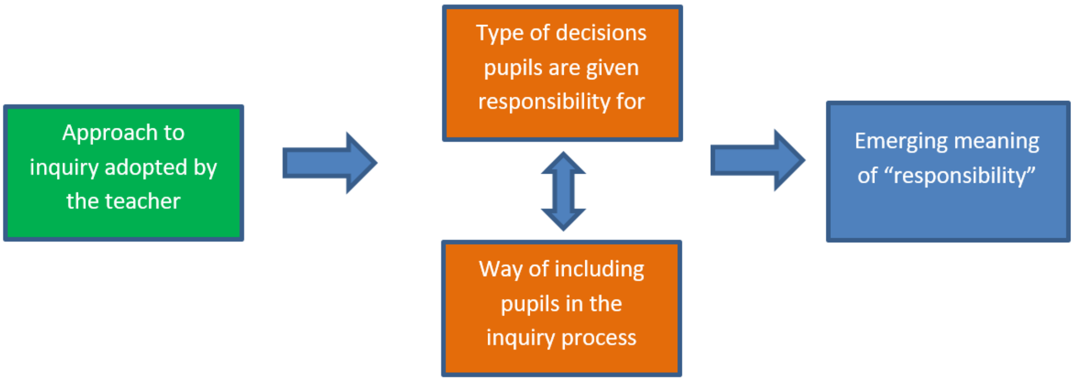

Figure 6. Inquiry and Responsibility

In the cases that were somehow closer to the scripted approach, we see emerging a particular meaning of "responsibility": pupils are responsible for the inquiry process in the sense that they are supposed to execute the tasks assigned by the teacher. In turn, the teacher provides the pupils with the support needed to help them do that.

If we look at the different inquiry phases, in the Orientation phase this meant that pupils received information concerning the inquiry that they were going to conduct and clear guidelines as to the kind of experiment they had to perform later in the Investigation phase. This is because, as we have reported above from an interview with teacher Laila, pupils solve *her* problem not their own.

We have seen a similar pattern in the Conceptualization phase, where the pupils had to provide an answer usually in the form of a guess to a question that had been already framed and conceptualized. In this regard, we mentioned above that teacher Urmas stressed that pupils should provide the kind of answer he expects.

The Investigation phase very much coincided with the experimentation, and that is the only moment in which – even in the highly scripted type of inquiry – the pupils become more active, as they are called to perform the experiment. As we have seen, this chiefly means taking measurements and using the equipment. Although pupils have shown more initiative in conducting the actual experiment, the teacher does not necessarily fade into the background but checks that pupils are progressing and often paces them up. Besides, the kind of activity the pupils are involved in is still limited in scope by what the teacher has previously prescribed. The same pattern is shown in the Conclusion phase, in which the teacher makes sure that the pupils have achieved what she/he already had in mind.

The main practical implication is that the chance of "doing RRI" is somehow de-potentiated, precisely because pupils are included as executors, which means that they are responsible for simply executing the teacher's instructions. This becomes problematic, because in doing so pupils may fail to establish a deeper contact with the complexity and uncertainty of the inquiry process and thus – we add – with doing RRI.[7] *It is the teacher who is actually taking responsibility*.

Indeed, we want to stress that we do not mean that the adoption of a more scripted approach is something wrong or something that should be avoided. It all depends on the purpose that the teacher assigns to the inquiry activity. As we have reported from the post-fieldwork interviews, teachers may have their own reasons to approach inquiry in a more instrumental way. Which means that applying inquiry learning serves the purpose of delivering content. In addition to that, inquiry learning may provide *anyway* a pedagogical tool that is more open to pupils' inclusion than other forms of teaching science.

Moving to those cases that were closer to the other end of the spectrum, we may argue that we have observed emerging a different meaning of responsibility. In less scripted inquiries the different pattern of inclusion adopted by the in the inquiry process led to a different dynamic: the decisions that pupils were supposed to make were different and the level of engagement or participation was different too. For example, in the Orientation phase pupils were given the chance to decide on the specific topic to investigate. Or, alternatively, they were actively involved in choosing the kind of equipment to use later in the experimentation or bringing their own, as it happened in the case of measuring the different temperatures. Regarding this specific example, we mentioned that teacher Liina stressed that asking to bring their own equipment is a way to make pupils feel more responsible, as the pieces of equipment are *their own*.

Moving on to the investigation phase, we have seen that this is the phase that offered ample room for pupils to decide. For example, we have seen that when teacher Liina let her second grade pupils decide where to dig the hole to bury the items they chose, not only did the pupils get more engaged but they also had to face a number of unexpected problems they had to deal with, which is what we called "inquiries within the inquiry" to stress their unexpectedness. Discussions also had a different role. They spread across the entire inquiry and the teacher was open to the contributions that pupils could give without expecting the "right answer". They also come about in a more spontaneous way or at least they are not necessarily forced upon, but more integrated in the inquiry process.

[7] Wang and Wen (2010) remarked that direct instruction and teaching can have limitations, as it restricts "the development of students' process skills and abilities to make judgment". Shamsudin and colleagues (2014) observed that it is indeed easier for teachers "to assist students with a step-by-step guide to acquire content rather than letting them do the activity on their own and get confused".

In these cases, the kind of participation or engagement was more open to pupils' genuine contribution. As we depart from a scripted approach, what we see is the progressive expansion of what we may call "the space of responsibility", in which pupils are given the chance to be included in the process in a more meaningful way, which positively affects the possibility of doing RRI. As the space of responsibility expands, pupils progressively cease to be the mere executors of an otherwise pre-determined script, for which they have to respond to the teacher. Conversely, they get more and more involved as *agents of* and *in* the inquiry, which is a central feature in RRI. The idea of a space expanding or shrinking – depending on the pattern of inclusion – helps us avoid seeing the whole issue in dichotomous terms, that is, "either or", but as something dynamically enacted and re-enacted (see Figure 7).

Figure 7. The expansion (and shrinking) of the space of responsibility

The main practical implication here is that the kind of responsibility that the pupils are given is of a different kind from what we have seen before. While it would clearly be an overstatement to say that they ceased to be responsible *to* the teacher, the pupils progressively came to have more *direct contact* with the inquiry process during all its phases. This chiefly means that they were given the chance to start exploring the matter at hand *for themselves*. This is what contributes to what Reed (1996) called *primary experience.*

So, "doing RRI" can be viewed as meaningful engagement or participation, which occurs when the relationship that the pupils have with inquiry is somehow less *mediated* by the teacher. Such meaningful engagement of participation in the inquiry, enabled by the teacher, allows the pupils to progressively take ownership and thus experience *first-hand* what it means to be responsible within an inquiry process that is – to some extent – open, and not predetermined in advance. In this sense, RRI should not be viewed exclusively as an ethical add-on, but it is precisely the prerequisite for those ethical discussions to emerge.

In this process of taking ownership, in which the space of responsibility expands for pupils, the teacher may come to adopt different roles: for example, that of an initiator of a process, a challenger, a discussant, the one who *invites* pupils to inquiring and/or even a companion in the inquiry process itself. Indeed, it is worth noting that from the teacher's point of view including pupils in the inquiry process (and thus leaving it open to their contributions) means accepting a certain level of uncertainty and unpredictability. That may come in conflict with what the teacher thinks she/he is expected to do, as we have seen in the quotes from the interviews. Besides, as we have already mentioned, time was an issue that teachers stressed as a major factor hindering the possibility of adopting a different inclusive pattern.

More in general, we may say that the same ambiguity characterizing responsibility may apply to teachers themselves, who may adopt a different pattern of inclusion, precisely because they feel compelled to respond and therefore held accountable to parents, school directors, the national curriculum, and ultimately society. This is something that inevitably takes us to a different type of path worth investigating in the future.

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Annex 1: Observation schema

Observations in the class focused specifically on the following moments:

1) identification of the different inquiry phases and their function;
2) transition from one phase to another;
3) order of the phases;
4) instructions given by the teacher at the beginning of the inquiry;
5) the main roles played by the teacher during each phase;
6) for what tasks the pupils were given responsibility in each phase.

Annex 2: Overview of the results

Orientation	Example 1	Example 2	Example 3
Background information on the topic	Delivered by the teacher directly	Delivered through a discussion initiated by the teacher	Searched for by the pupils divided into groups without direct teacher's assistance
Specific problem to address	Identified by the teacher beforehand	Identified by a discussion initiated by the teacher	Identified by the pupils divided into groups without direct teacher's assistance
Conceptualization			
Formulation of the research question or hypothesis	Provided by the teacher	Formulated through a discussion led by the teacher	Autonomously formulated by the pupils divided into groups
Investigation			
Design of the experiment	Provided by the teacher through the worksheet	Articulated in a discussion led by the teacher, in which pupils gave their own contribution	Articulated autonomously by the pupils divided into groups
Experimentation	Performed by the pupils while the teacher checked that everything was done correctly	Delivered through a discussion initiated by the teacher	Performed by the pupils divided into groups
Compilation of the results	Prompted by questions provided in the worksheet	Prompted by a discussion led by the teacher	Performed by the pupils in the class before the teacher
Conclusion			
How conclusions were reached	By writing down the results of the demonstration	Triggered by teacher's questions	None

Scripted → Open

6. Study 5. Incidence of 21st Century Skills and Competences and RRI in Ark of Inquiry activities

6.1. Introduction

The Ark of Inquiry research and development project has, during the time span of four years, aimed at increasing pupils' science literacy skills and understanding of Responsible Research and Innovation (RRI). The project has sought to reach its objectives through, for example, training teachers and making inquiry activities accessible through the Ark of Inquiry platform. During the implementation phases of the project, the activities have been noticed to support the development of pupils' scientific investigation skills as well as 21st century skills in more general terms. Twenty-first century skills, together with the values of Responsible Research and Innovation (RRI), have also been highlighted as important educational contents in recent reports by the European Union (e.g., Hazelkorn et al., 2015). Therefore, the main objective of our research was to investigate how well the inquiry activities of the Ark of Inquiry project cover 21st century skills and RRI contents.

In this research, twenty-first century skills are defined as essential competencies of the 21st century, which, according to scientific literature (e.g., Ananiadou & Claro, 2009; Griffin, Care, & McGaw, 2012), have also been referred to as *21st century skills* or *competencies* and *key competencies*. Literature often refers to both *skills* and *competencies,* of which the latter is usually understood as a concept of wider and broader faculty, although a skill can also be acknowledged as a more complex scheme and not only as a specific skill in its traditional terms (Ananiadou & Claro, 2009; OECD, 2016a). The assessment of the Ark of Inquiry activities reported in this research is based on a synthesis of five carefully selected frameworks of 21st century skills, since even though research on 21st century skills has increased during the last decade (Voogt & Roblin, 2012) and the definitions of different frameworks seem to share many common characteristics (e.g., Binkley, Care, & McGaw, 2012; Griffin, Care, & McGaw, 2012; Koening, 2011; Moylan, 2008), the research community is missing a commonly acknowledged and neutral definition of 21st century skills (Ananiadou & Claro, 2009).

6.2 Methodology

Selection of documents

The research aiming towards assessing inquiry activities from the Ark of Inquiry platform was initiated by creating a synthesis of the following 21st century skills documents developed by widely known organizations, institutions, and research projects:

1) *Framework Definitions* (Partnership for 21st Century Learning, 2015),
2) *The Survey of Adult Skills: Reader's Companion* (OECD, 2016a),
3) *Defining Twenty-First Century Skills* (ATC21S) (Binkley et al., 2012),
4) *New Vision for Education Unlocking the Potential of Technology* (World Economic Forum, 2015),
5) *Key Competences for Lifelong Learning: A European Reference Framework* (European Parliament, 2006).

The documents were selected based on the similar precision of the contents as well as the quality of the documents in order to avoid imbalance between the source materials. All of the selected documents represent pieces of fundamental research on 21st century skills and are referred to in most of the published peer-reviewed studies (see, e.g., Ananiadou & Claro, 2009; Kereluik, Mishra, Fahnoe, & Terry, 2013). The above-mentioned frameworks were also selected on the basis of the variety of countries that have been involved in the development processes of the frameworks.

The synthesized 21st century skills framework

The five selected framework documents were analysed by using the principles of content analysis. The analysis aimed at distinguishing recurring schemes of which some were combined according to how clearly they were related (see Annex A for a detailed description of the analysis). The analysis resulted in a synthesized 21st century skills framework consisting of three main categories and eight subcategories.

Table 1. The synthesized framework of 21st century skills[8]

1. Learning Skills	
	- *Critical and Creative Thinking and Problem Solving (6, 8, 9, 11)*
	- *Metacognition, Lifelong Learning (7, 10, 12, 13, 20)*
2. Life Skills	
	- *Communication *RRI (1)*
	- *Collaboration (2)*
	- *Cultural Awareness, Citizenship Skills *RRI (5, 12, 13, 15, 17)*
3. Literacy Skills	

[8] In brackets: The schemes included in the subcategory in question as presented in Table 4 of Annex A.

- *Information and Media Literacy (4)*
- *ICT Literacy (3)*
- *Mathematical and Scientific Literacy (14)*

The first category, Learning Skills, describes ways of learning that are suitable and effective in the 21st century economies and societies. It includes the subcategories Critical and Creative Thinking combined with Problem Solving Skills, which are all essential 21st century skills according to our research and previous literature (Agrusti, 2013; Binkley et al., 2012; Kereluik et al., 2013; Silva, 2009; Voogt & Roblin, 2012). Metacognition and Lifelong Learning are also essential Learning Skills, as they emphasize, for example, the active role of the learner in any learning situation.

Life Skills includes competencies and skills related to interaction and working with others, e.g., Communication and Collaboration. The Cultural Awareness and Citizenship Skills subcategory emphasizes values and ethics relevant today and in the future, e.g., sustainable development, environmental issues, cultural diversity, tolerance, knowledge of democratic citizenship skills, and the ability to act as a member of society and the professional community in a responsible manner.

Literacy Skills, as the name suggests, contains the most concrete skills of the framework. The Information and Media Literacy subcategory refers to multi-literacy, an entity including skills of rating the reliability of information in different media and searching for proper information, whereas the ICT Literacy subcategory refers to competencies in utilizing ICT efficiently in a specific context. Finally, the Mathematical and Scientific Literacies subcategory addresses the importance of logical, linear, and consistent ways of working and thinking, including basic skills and knowledge of how to conduct experiments and investigations.

Responsible Research and Innovation, as defined in the Ark of Inquiry, is included in all of the subcategories; however, only when the activity involves reflective and higher-order thinking, that is, when the activity is given a rating of 3 (for details on the assessment of the activities, see Annex B and D). Subcategories that have a strong emphasis on the contents of RRI are marked with an asterisk in Table 1 on the previous page. These subcategories are Cultural Awareness, Citizenship Skills, and Communication, and they cover RRI contents regardless of the rating of the activity.

6.3. Results

The assessment of the Ark of Inquiry activities was initiated by selecting a sample of 40 inquiry activities from the Ark of Inquiry platform by using a stratified sampling technique (see, e.g., Thompson, 2012). The activities were stratified according to the author of the activity, the age of the target group, the proficiency level of the activity, the language of the activity, and the type of the activity (for details on the sample, see Annex C). By the type of the activity we refer to the nature of the activity – whether it is an online-lab activity, which at least to some extent is carried out in a virtual learning environment, or a traditional classroom activity. All of the analysed activities were in Finnish or English because the assessment required a thorough understanding of the contents of the activities, and the research was primarily thought to provide useful information for teachers in Finland.

The selected activities were rated on a scale from 0 to 3 based on the available information in the activity descriptions. Each activity was given a rating for each of the eight subcategories of the synthesized 21st century skills framework according to how well the contents of the activity corresponded to the criteria of the assessment tool created for this research. Levels one, two, and three consisted of criteria regarding the extent and depth to which the content is covered during the activity, and if the activity did not cover any of the criteria, it was given a zero for that specific skill. The assessment tool in its simplified form is presented in Annex B, and an example on how the activities were rated can be found in Annex D.

Coverage of different 21st century skills subcategories

Based on the assessment of the activities, all of the 40 Ark of Inquiry activities selected for the study included some contents of the 21st century skills. The average of how well the activities covered 21st century skills was 1.88 on a scale from 0 to 3. The value can be considered quite high given that each activity was assessed separately and given a separate rating for each subcategory of 21st century skills. Furthermore, it is unreasonable to assume that a single activity would cover all 21st century skills at the same time and on a high level. As can be seen in Table 2 below, there is quite a large variation in how well the different subcategories of 21st century skills were covered.

Table 2. Descriptives of the subcategories of 21st century skills in the Ark of Inquiry activities [9]

Category	Subcategory of 21st century skills	M	SD	Min	Max
Learning Skills	Critical and Creative Thinking, Problem Solving	2.10	0.955	0	3
	Metacognition and Lifelong Learning	2.10	0.754	1	3

[9] *Strong RRI component included

Life Skills	Communication*	1.94	0.938	0	3
	Collaboration	1.97	1.000	0	3
	Cultural Awareness and Citizenship Skills*	0.95	1.141	0	3
Literacy Skills	Information and Media Literacy	2.43	0.844	0	3
	ICT Literacy	1.35	0.949	0	3
	Mathematical and Scientific Literacies	2.45	0.714	1	3
21st century skills	**All categories**	**1.88**	**0.638**	**0.50**	**2.75**

The analysis revealed that 42.5% of the analysed activities covered all of the 21st century skills subcategories at the same time, i.e. received at least a rate of 1 for all of the eight subcategories. It is also worth highlighting that 116 (36.25%) out of 320 values (40 activities x 8 subcategories) were given a rating of 3, whereas there were only 12 (3.75%) missing values out of the maximum of 320 values. Some of the missing values resulted from the fact that some activities did not include, for example, a description of the way of working (e.g., individual work, pair work, etc.); therefore, it was not possible to assess the activity from the perspective of collaboration.

The average ratings of the subcategories ranged from 0.95 to 2.45, as can be seen from Table 2 above. The subcategory Mathematical and Scientific Literacy was covered on the highest level (2.45), followed closely by the subcategories Information and Media Literacy (2.43), Critical and Creative Thinking and Problem Solving (2.10), and Metacognition and Lifelong Learning (2.10). This result indicates that the Ark of Inquiry activities have great potential for teaching these 21st century skills. The subcategory of Cultural Awareness and Citizenship Skills received the lowest mean value (0.95), which was quite expected due to the scientific nature and emphasis of the activities. However, there were a few activities that received a rate of 3 for Cultural Awareness and Citizenship Skills; these activities included topics that encouraged pupils to elaborate and reflect on the activity from the perspective of the society, environment or economy.

An interesting result was that the subcategory of ICT Literacy (1.35) received the second lowest mean, while the other subscales in the category of Literacy Skills, namely Information and Media Literacy and Mathematical and Scientific Literacy, reached the highest mean values (2.43 and 2.45, respectively). This result implies a need to address the quality of ICT related tasks even more when preparing inquiry activities in the future.

Results from the perspective of the activities

When taking a closer look at the activities, we found that the inquiry activities collected in the Ark of Inquiry project are well suited for teaching 21st century skills based on the rather high average coverage of the different 21st century skills subcategories. However, it is worth highlighting that the high standard deviations, ranging from 0.714 to 1.141 on a scale from 0 to 3, indicate a fairly large variation in how well the activities cover different 21st century skills. The diversity of the activities was also noted when comparing the average scores of the individual activities, which varied from 0.5 to 2.75 (for more details see Annex E). The large variation between the individual activities may partly be explained by the different emphases and topics of the activities. The activity which received the lowest average score (0.5) was a Finnish physics activity for 12-year-old pupils called *Ihmeellinen vesi (Incredible water)*, which addresses the phenomena of surface tension and capillary action. It includes several experiments that are carried out with the help of highly structured and specific instructions and the teacher's examples and demonstrations. In contrast to the activity that received the highest average score, *Estimating Density of an Endangered Plant Species in a Named Ecosystem,* it is much more teacher-led and structured. The latter activity was rated very high since it involved discussions including ethical dimensions in addition to the contents of investigating ecosystems. The activity also entails practising critical thinking, as pupils are asked to discuss the limitations of their studies and findings. Additionally, it includes practising communication and collaboration skills, as the different phases of the activity are conducted in small groups.

21st century skills across proficiency levels

The Ark of Inquiry activities are divided into three proficiency levels, which demonstrate the different levels of inquiry challenges. One of the main objectives of dividing the activities according to proficiency levels was helping teachers in differentiating activities according to their pupils' skills. Detailed descriptions of the proficiency levels are found in Deliverable D1.1 (de Vries et al., 2014). The descriptives on how the activities of the three proficiency levels covered 21st century skills on average are presented in Table 3.

Table 3. Coverage of all 21st century skills in activities of different proficiency levels

Proficiency level	n	M	SD	Min	Max
Novice	14	1.61	0.742	0.50	2.50
Basic	21	2.04	0.527	1.13	2.75
Advanced	5	1.93	0.689	0.83	2.50
All activities	**40**	**1.88**	**0.638**	**0.50**	**2.75**

As can be noticed, there were no significant (p=.141) differences between the activities of different proficiency levels in how well they covered 21st century skills. However, as can be seen from the table above, the activities targeted at novice learners were rated to have a slightly lower average coverage of 21st century skills when compared to the activities of the other two proficiency levels. In the context of the Ark of Inquiry, novice level activities are mostly well structured and the implementation does not require a lot of previous knowledge about scientific inquiry. It was therefore assumed that these activities included easier contents, assignments, and objectives of 21st century skills. In addition, the imbalance between the English and Finnish activities in terms of advanced level activities resulted in an analysis of only five activities of the advanced proficiency level, making the groups of activities of different proficiency levels incomparable in size, and the results are therefore only directional.

6.4. Practical relevance

The results of this study are in general very encouraging, since none of the analysed Ark of Inquiry activities have been explicitly designed for teaching 21st century skills. The activities of this study set a great example of inquiry activities that also seem to adapt well to the teaching of 21st century skills. Based on this research, 21st century skills and competencies should not just be considered as unique and novel contents but rather regarded as skills that can be taught as part of well-designed and existing inquiry activities.

To conclude, the results of the evaluation of the inquiry activities indicate that there is a clear link between 21st century skills and the inquiry approach. Inquiry learning promotes learner-centred learning and encourages pupils to take an active role in their learning processes, which is also an essential skill in the 21st century. Based on the results of this study, it seems that activities that are more open rather than very structured and teacher-led have a better chance of promoting 21st century skills. In teaching and learning 21st century skills, it is important to emphasise the opportunities for learners to think for themselves, plan their own work, think critically and evaluate the process of their learning.

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Appendix 1

Description of the content analysis of the five framework documents

The five selected framework documents (Binkley et al., 2012; European Parliament, 2006; OECD, 2016a; Partnership for 21st Century Learning, 2015; World Economic Forum, 2015) were analysed by using the principles of content analysis. The aim was to distinguish, compare, and combine the most emphasized skills of the frameworks and to create a neutral, theoretically grounded framework for developing an assessment tool for the evaluation of the Ark of Inquiry activities. The analysis was initiated by closely reading the framework documents, breaking down the texts into smaller content units and listing these content units of each document to receive a detailed understanding of the source material. The listing of the content units was followed by a division of the contents by their meanings into schemes. The recurring schemes were then collected (see Table 4), and some schemes that were closely related were combined already at this stage of the analysis (e.g., number 5 in Table 4. Cultural awareness, Citizenship). Recurring schemes that did not relate to any other schemes were placed in the table on their own.

Table 4. The schemes of the five 21st century skills frameworks[10]

Mentioned in all the frameworks	Mentioned in most of the frameworks	Mentioned in a few of the frameworks	Mentioned in one of the frameworks
1. Communication (5)	8. Problem Solving (4)	16. Entrepreneurship (2)	17. Financial literacy (1)
2. Collaboration, Teamwork (5)	9. Critical Thinking (3)		18. Flexibility (1)
3. ICT Literacy (5)	10. Learning to Learn, Lifelong Learning (3)		19. Leadership (1)
4. Information Literacy (5)	11. Creativity, Innovation (4)		20. Accountability (1)
5. Cultural awareness, Citizenship (5)	12. Responsibility (3)		
6. Creativity (5)	13. Adaptability (3)		
7. Metacognition (5)	14. Numeracy, Mathematics, Science (3)		
	15. Career, Work (3)		

[10] The number in the brackets indicates the number of frameworks that included the specific scheme.

The content analysis was followed by a process during which the schemes presented in Table 4 were yet again combined with each other if the contents were clearly related, e.g., Innovation was included in Creativity; responsibility, career and work, and financial literacy were included in Cultural awareness and Citizenship; and adaptability was included in Metacognition. Details of which schemes (numbers noted in brackets) were arranged under which categories in the final 21st century skills framework are shown in Table 1 in section 2.2. However, it is worth highlighting that Entrepreneurship, Flexibility, and Leadership were not included under a specific subcategory of the framework as they were regarded qualities that are contained in more than two subcategories simultaneously.

Appendix 2

Creation of the assessment tool for analysing the Ark of Inquiry activities

The assessment tool with a scale from 0 to 3 was developed on the basis of the created framework of 21st century skills and by conducting a more elaborate content analysis on the five original framework documents and four other documents carefully chosen STEM-themed research documents11 in addition to the contents of some activities from the Ark of Inquiry platform. The scale of the assessment tool adapts the same patterns as were used for creating the rating of the proficiency levels of the Ark of Inquiry activities (see, e.g., de Vries, Mäeots, Siiman, & Veermans, 2014). A generalised structure of the assessment tool is shown in Table 5.

Table 5. The simplified and generalised structure of the assessment tool

Rate	Rationales for evaluating the activities
0	The theme did not appear in the material
1	Structured and well-defined activity or problem space Basic knowledge and functions/competences/skills Understanding and awareness of issues and skills related to the subcategory Working under structured guidance, teacher-led studying and working
2	Semi-structured activity or problem space Pupils work independently but through guidance or semi-structured steps The activity might include fairly structured instructions for pupils but at least some of the phases of the activity call for critical thinking and self-management of pupils

[11] by the European Commission (2015), OECD (2016b), Mullis & Martin (2013), and Next Generation Science (2013)

3	Open-ended activity or problem space Learner-directed teaching Pupils are active participants in planning and implementation of the activity Pupils evaluate and reflect upon their own learning Attention is allocated on ethics and the activities' impact on the society Pupils plan and guide their own work and inquiry activity Reflection and evaluation (self-evaluation/self-assessment, peer assessment/evaluation, peer feedback) The significance for the society Integration of ethical dimensions and RRI aspects

Appendix 3

Table 6. The analysed activities (N=40)

Variable	n	%
Language		
Finnish	20	50.00
English	20	50.00
Proficiency Level		
Novice	14	35.00
Basic	21	52.50
Advanced	5	12.50
Age Group		
7- to 12-year-olds	13	32.50
13- to 18-year-olds	9	22.50
Suitable for both age groups	18	45.00
Type of Activity		
Online lab	14	35.00
Lesson plan	26	65.00

Appendix 4

Assessing an inquiry activity from the Ark of Inquiry platform

As an example, an activity was given a 1 for *ICT Skills* if it included practising of basic skills within the field of ICT. Basic skills include, for example, using a text editing or data analysis program on a simple level by writing or inputting data. To receive a rating of 2, the activity was required to contain applied use of ICT, such as conducting basic data analysis procedures or editing files, but not only inputting information. To be given a rating of 3, the activity was required to clearly encourage learner-centred learning during which the pupil should use ICT critically and responsibly in a creative way, that is, figure out how to utilize ICT in the context of his or her task and according to his or her objectives. In addition, the activity should include reflections on the ethical issues involved in utilizing ICT. As mentioned before, elements of RRI are seen to be included in the highest level of each subcategory: therefore, if the activity has been given a rating of 3, it has been regarded as an activity that promotes responsible and innovative research practices. The subcategory was coded with a missing value if it was impossible to evaluate the content of a specific subcategory on the grounds of the provided information in the description of the activity.

Appendix 5

Table 7. The result of the assessment of the inquiry activities (N=40)

Categories	**Literacy Skills**			**Life Skills**			**Learning Skills**		
Activity	ICT Literacy	Information and Media Literacy	Mathematical and Scientific Literacy	Collaboration	Communication	Cultural Awareness and Citizenship Skills	Metacognition and Lifelong Learning	Critical Thinking and Problem Solving	**Total**
Kotitalouden ja fysiikan pesuaineprojekti	2	2	1	*	*	0	1	1	**1.17**
Kemiaa vedestä	2	3	3	1	1	1	2	3	**2.00**
Maidoista parhain	2	3	3	3	3	1	2	3	**2.50**
Kasvupaikkatekijöiden tutkimus	3	3	3	3	3	0	3	3	**2.63**
Mistä Duudsonin putoaminen riippuu	2	3	3	3	2	0	2	3	**2.25**
Lähialueen kasvien tunnistaminen ja oman kasvion kokoaminen	2	3	2	1	2	0	2	2	**1.75**
Nimikkopuut ja vuodenajat	2	3	2	3	3	0	3	1	**2.13**
Kyy puree – mikä avuksi	2	3	3	3	2	1	3	3	**2.50**
Paperi paikallaan – tutkimuksia paperista	0	3	2	2	2	0	2	3	**1.75**
Is It Good to Be Beautiful?	1	3	3	1	1	1	3	3	**2.00**
Should Dangerous Household Chemicals Be Banned? Yes/No	1	3	3	2	3	2	3	2	**2.38**

Craters on Earth and Other Planets	2	3	3	2	3	2	3	2	**2.50**
The Color of the Light	1	3	3	0	0	0	3	3	**1.63**
Sinking and Floating	1	3	2	0	0	0	3	2	**1.38**
Mistä voi saada luotettavaa tietoa lääkkeistä?	3	3	2	2	2	2	2	3	**2.38**
Öljyonnettomuus	0	1	1	*	1	3	*	1	**1.17**
Raksuttaako rakenteet – korkea rakennelma	0	2	2	3	1	0	2	1	**1.38**
Yritykset kriisissä	2	3	3	3	2	3	2	3	**2.63**
Biodiversity	2	2	3	1	3	3	2	3	**2.38**
Food	2	3	3	3	3	3	2	3	**2.5**
Heart Matters	2	3	3	3	2	0	2	1	**2.00**
Black Box	0	2	3	*	*	0	2	3	**1.67**
The Language of Nature: Winter Comes to Our Campus	0	1	2	2	1	0	1	1	**1.00**
Forensic Science: DNA Fingerprint	0	1	1	*	*	1	1	1	**0.83**
Our Daily Bread	1	3	3	3	2	3	3	3	**2.63**
Plant Growth	1	2	3	1	1	0	3	2	**1.63**
How Do People Travel When They Go On Holiday?	1	2	2	1	3	2	3	2	**2.00**
Janoiset sankarit	2	3	3	3	2	0	2	3	**2.25**
Kuivauksen monet mahdollisuud	2	3	3	3	2	0	3	3	**2.38**

et								
How to Make Hard Boiled Eggs That Are Easy to Peel?	2	3	3	3	3	0	3	3	**2.50**
Ihmeellinen vesi	0	0	1	1	1	0	1	0	**0.50**
Hiusten kemiaa	0	2	2	2	1	1	1	1	**1.25**
Hiilipuu.fi	1	2	2	1	1	1	1	1	**1.25**
Construction of Water Carrier	0	1	2	*	*	0	1	1	**0.83**
Valaise viisaasti	2	3	2	1	3	3	2	1	**2.13**
Rocket Science/Newton's Third Law	2	3	3	1	3	1	2	3	**2.25**
Erastothenes Experiment in Primary Schools	1	1	3	1	1	0	1	1	**1.13**
Pulleat vaahtokarkit	0	1	1	*	*	0	1	1	**0.67**
Car Pollution	2	3	3	2	2	1	2	3	**2.25**
Estimating the Density of an Endangered Plant Species in a Named Ecosystem	3	3	3	3	3	3	2	2	**2.75**

7. Study 6. Pupils' On-Task Interest While Conducting Various Inquiry Activities

7.1. Introduction

During the last decade, studies have reported a decrease in pupils' interest in science (e.g., OECD, 2006; Rocard et al., 2007; Sjøberg & Schreiner, 2010). Furthermore, a decrease in university students graduating with a science-related degree has been noticed on a European level (Ranguelov, De Coster, Norani, & Paolini, 2012). The decline in interest in Science, Technology, Engineering and Mathematics (STEM) education may derive, for example, from the deficiency of teacher training and ineffective science teaching methods that are not very appealing to pupils (Agrusti, 2013). The declined level of pupils' interest is rather worrying, since it has also been reported to have an impact on learning and pupils' future performance (Alexander, Kulikowich, & Jetton, 1994; Murphy & Alexander, 2002; Schiefele, 1999).

Specific concerns have arisen regarding the gender gap in terms of pupils' interest in science (Gokhale, Rabe-Hemp, Woeste, & Machina, 2015; MacLean, 2017; Rocard et al., 2007). According to Rocard et al. (2007), girls' interest in science and mathematics has been reported as significantly lower than boys'. Similar results have also been shown in studies investigating freshman and senior students majoring in science-related subjects (Gokhale, Rabe-Hemp, Woeste, & Machina, 2015).

Interest has also been found to be related to subject choices that pupils make when attending secondary education. In primary education, both genders tend to study the same subjects, but when it comes to higher education, males have a stronger tendency to choose to study STEM subjects when compared to females (MacLean, 2017). The gender gap can also be perceived when comparing adolescents' career aspirations. According to the PISA results from 2015, girls are more interested in working as doctors, veterinarians and nurses, whereas boys are more interested in working as engineers, scientists, architects and ICT professionals (OECD, 2016).

The aim of this study was to analyse how interesting pupils of different age groups and varying countries find inquiry activities and whether the interest varies between boys and girls. In this research, we define interest according to the definition of Hidi and Renninger (2006). They define it as a person's "psychological state of engaging or the predisposition to re-engage with particular classes of objects, events, or ideas over time" (Hidi & Renninger, 2006, p. 112), which may refer to an individual's situational[12] or individual interest (Hidi &

[12] Later *on-task interest*, which is taken as a synonym for *situational interest* in the context of this study.

Renninger, 2006). According to Krapp (2007), situational interest is seen as a state which occurs in a limited period of time and is triggered by external factors, whereas individual interest is related to a more stable affection towards specific topics. The topic of situational interest is extremely intriguing, since it has potential to increase long-term interest (Ainley, Hidi, & Berndorff, 2002; Hidi & Harackiewicz, 2000; Mitchell & Gilson, 1997). In this research, pupils' interest in an inquiry activity was examined through repeated measures, at the beginning and at the end of the activity, to collect data not only on pupils' on-task interest but also to observe the change in their level of interest throughout the activity.

This study aimed at answering the following research questions:
1. What is the level of pupils' on-task interest in inquiry learning?
2. Are there differences in pupils' on-task interest in inquiry learning for the following groups: gender of pupils; age of pupils; country of pupils; domain of the activity?

7.2. Methodology

The data was collected during the large-scale implementation phase of the Ark of Inquiry project, which was initiated in March 2016 and lasted for 24 months. During the implementation phase, teachers and pupils were asked to conduct various inquiry activities in their science classrooms.

Data on pupils' on-task interest was collected through self-report questionnaires where pupils were asked to rate their interest in the inquiry activity at repeated measurement times: at the beginning of the activity, while working on the activity, and at the end of the activity. The participating pupils conducted inquiry activities chosen from the Ark of Inquiry platform or designed by their own teacher. The implemented activities followed the principles of the five-phase inquiry cycle model (Pedaste et al., 2015). Since the activities were self-selected or -designed by the teacher, the lengths and the topics of the activities varied throughout the sample. The sample of this study is presented in Table 1.

Table 1. Distribution of pupils across the participating countries

Project Country	Gender	n	7–12 years old	13–18 years old
AUT (n = 82)	Female	39	39	–
	Male	43	43	–
BE (n = 134)	Female	54	54	–
	Male	80	80	–
CY (n = 333)	Female	173	81	92
	Male	160	59	101
FI (n = 964[a])	Female	472	400	72
	Male	484	401	83
GR (n = 431[b])	Female	216	216	–
	Male	200	200	–
IT (n = 111[c])	Female	47	42	5
	Male	28	22	6
NL (n = 59)	Female	28	26	2
	Male	31	26	5
TR (n = 643)	Female	316	316	–
	Male	327	327	–
(N = 2757)		2698	2332	366

Notes

[a] FI: 8 pupils did not report their gender.

[b] GR: 15 pupils did not report their gender.

[c] IT: 36 pupils did not report their gender.

The sample of this study consisted of 2757 pupils (1345 females and 1353 males, 59 did not report their gender) from eight of the (total of 12) Ark of Inquiry partner countries (Austria, Belgium, Cyprus, Finland, Greece, Italy, the Netherlands, and Turkey). The participants' ages ranged between 7 and 18 years. Despite the high number of participants, it is worthwhile to highlight that the two age groups were not equal in terms of the number of pupils belonging to the groups. The group of 7- to 12-year-old pupils included 2384 pupils, whereas the group of 13- to 18-year-olds only included 373 pupils. This imbalance is important to acknowledge when interpreting the results.

The on-task interest questionnaire used for this study is based on the previous work of Tapola, Jaakkola, and Niemivirta (2014). The framework consists of five identical sets of statements, each to be completed at separate measurement points during an inquiry activity: at the beginning of the activity, while working on the activity, and at the end of the activity. Each set of statements included three items that measured pupils' on-task interest in the inquiry activity, the topic of the inquiry lesson, and the working method of the inquiry lesson. At the end of the activity, pupils were also asked to indicate whether they were interested and willing to learn more about the topic. Additionally, they were asked to evaluate how important and useful they felt the topic was and how successful the collaboration with other pupils had been during the activity. The items related to pupils' interest were rated on a seven-point Likert scale ranging from 1 to 7 (1 = not interesting at all, 7 = very interesting).

To reach the objectives of this study, that is, to investigate pupils' on-task interest in the inquiry activity at the beginning and at the end of the activity session and to find out whether pupils' on-task interest changed during the inquiry activity, a paired samples t-test was conducted based on the data of two measurement points of the following item: "This lesson seems to me… 1 = not interesting at all, 7 = very interesting". Since many countries did not collect data on pupils' on-task interest while they were working with the activity, the analyses were conducted only by using the data from the beginning and end of the activity sessions. Following the analysis of the whole sample, an additional t-test was performed by splitting the data by gender, the two age groups (aged 7–12 and aged 13–18) and the different countries. The data were also analysed from the perspective of the domain of the activity. Independent samples t-test was used to compare female and male pupils and the pupils of the two age groups.

7.3. Results

Pupils' on-task interest in the inquiry activity

Pupils' on-task interest in the inquiry activity was determined by calculating the mean values for the first and the last measurement point by using the answers of all respondents (N=2757) (see Table 2). In addition, the overall mean of the two measurements was calculated, resulting in an average of 5.55 on a scale from one to seven (SD=1.40). Pupils' on-task interest at the beginning and at the end of the inquiry activity is presented in Table 2.

Table 2. Pupils' on-task interest at the level of the entire sample

Measurement point	n	M	SD	Min	Max
At the beginning of the inquiry activity (pre)	2567	5.35	1.551	1	7
At the end of the inquiry activity (post)	2493	5.85	1.501	1	7

A paired samples t-test was also conducted to compare pupils' on-task interest at the beginning and at the end of the inquiry activity. However, as the sample (N=2757) included 454 (16.5%) missing values, out of which 190 (6.9%) were missing from the first measurement time and 264 (9.6%) were missing from the last measurement time, and none of the missing values were replaced, the total sample for the t-tests was 2313 pupils.

Based on the results of the paired samples t-test, we found that pupils expressed a very high interest in inquiry learning already at the beginning of the activity session (M=5.40, SD=1.526) and their interest was even higher at the end of the last inquiry learning session (M=5.89, SD=1.484). We also found that the change in pupils' on-task interest was significant t(2312)=-16.315, p=.000, indicating that the inquiry activities were not only able to maintain but also increased pupils' on-task interest.

Gender and age

For the data analysis pupils were divided into groups according to their gender and age. Two age-related groups were formed by splitting the pupils' age range (7- to 18-year-old) in half: group 1 included pupils in the age range of 7 to 12 years of age, and group 2 included pupils in the age range of 13 to 18 years of age. By splitting the age range in half, we managed to form two groups that also corresponded to the division of pupils attending upper and lower secondary school. Of the participating pupils, 86.47% were 7 to 12 years old (1174 females and 1158 males, 52 unknown) and the rest were 13 to 18 years old (171 females and 195 males, 7 unknown).

An independent samples t-test was performed to find out whether female (n=1255) and male (n=1253) respondents differed in terms of their on-task interest in the inquiry activity. A significant difference was found between female (M=5.46, SD=1.489) and male respondents (M=5.21, SD=1.605) at the beginning of the inquiry activity session (t(2506)=-3.938, p=.000), as girls reported a higher interest when compared to boys. At the end of the activity, the significant difference between genders had disappeared (t(2438)=-.426, p=.670; females (n=1222), M=5.85, SD=1.487; males (n=1218), M=5.83, SD=1.518). This result indicates that inquiry activities might help reduce the gender gap in pupils' on-task interest in STEM domains.

Table 3. Interest at the beginning and at the end of the inquiry activity

	At the beginning					At the end				
Variables	*n*	*M*	*SD*	*t*	*p*	*n*	*M*	*SD*	*t*	*p*
Gender				-3.938	.000				-.426	.670
Male	1253	5.21	1.61			1218	5.83	1.52		
Female	1255	5.46	1.49			1222	5.85	1.49		
Age				2.949	.003				3.277	.001
7 to 12	2205	5.39	1.54			2175	5.88	1.50		
13 to 18	362	5.12	1.63			318	5.59	1.47		

By conducting the same analysis for the two age groups, a significant difference was found between the younger (7 to 12 years old) and the older (13 to 18 years old) pupils based on the data of the first measurement, where the younger pupils scored slightly higher (M=5.39, SD=1.535) than the older pupils (M=5.12, SD=1.627, t(2565)=3.074, p=.002). The difference was significant, t(2491)=3.277, p=.001, also at the end of the activity session, with 7–12-year-old pupils scoring higher (M=5.88, SD=1.502) than 13–18-year-old pupils (M=5.59, SD=1.468) (see Table 3).

Pupils' on-task interest in project participant countries

The data of pupils' on-task interest were also analysed by countries. The means of the pre-test varied from 5.07 (BE) to 6.38 (IT) and from 4.89 (AUT) to 6.46 (IT) in the post-test. The averages of the pupils, females and males and the pupils of the two age groups, from different countries, are displayed in Table 4 below. The trend between the two measurement points was positive, as the pupils' on-task interest increased during the activity in all country samples. The details of the two measurement points are presented in Table 4.

Table 4. Descriptions of pupils' on-task interest by country, gender and age of pupils [13]

Country		Pre/ post	Male		Female		7–12-year-olds		13–18-year-olds		All	
	n[1]		M	SD	M	SD	M	SD	M	SD	M	SD
AUT	–	–	–	–	–	–	–	–	–	–	–	–
	82	post	5.23	1.231	4.51	1.374	4.89	1.343	–	–	4.89	1.343
BE	134	pre	5.16	1.267	4.94	0.998	5.07	1.167	–	–	5.07	1.167
	132	post	5.51	1.266	5.09	1.248	5.34	1.271	–	–	5.34	1.271
CY	333	pre	5.56	1.495	5.68	1.406	5.53	1.505	5.68	1.406	5.62	1.448
	333	post	6.00	1.229	6.00	1.089	5.86	1.315	6.10	1.018	6.00	1.156
FI	863	pre	5.04	1.542	5.16	1.520	5.30	1.469	4.15	1.483	5.11	1.532
	731	post	5.52	1.574	5.46	1.585	5.67	1.510	4.34	1.571	5.49	1.584
GR	425	pre	5.31	1.873	5.56	1.796	5.42	1.841	–	–	5.42	1.841
	411	post	5.55	1.917	5.65	1.886	5.59	1.894	–	–	5.59	1.894
IT	111	pre	6.21	0.833	6.62	0.573	6.32	0.810	6.67	0.485	6.38	0.775
	108	post	6.25	0.844	6.57	0.695	6.43	0.808	6.61	0.502	6.46	0.766
NL	59	pre	5.26	1.770	5.32	1.307	5.29	1.551	5.29	1.704	5.29	1.554
	58	post	5.87	1.907	5.82	1.679	5.73	1.866	6.71	0.488	5.84	1.785
TR	642	pre	5.14	1.624	5.59	1.303	5.36	1.490	–	–	5.36	1.490
	638	post	6.36	1.220	6.56	0.899	6.46	1.078	–	–	6.46	1.078
TOT.	2567	pre	5.21	1.605	5.46	1.489	5.39	1.535	5.12	1.627	5.35	1.551
	2493	post	5.83	1.518	5.85	1.487	5.88	1.502	5.59	1.468	5.85	1.501

[1] The n value represents all pupils from each country participating in the study.

The change in pupils' on-task interest within the different countries was investigated by a paired samples t-test. The trend between the two measurement points was positive, and pupils' overall interest increased significantly in the case of all other countries ($p<.05$) except for Italy ($p=.131$); however, it is worth highlighting that Italian pupils rated their interest very high already at the beginning of the activity compared to pupils from the other countries.

[13] The results presented in the table do not include pupils that did not report their gender (n=59).

Austrian pupils did not respond to the questionnaire at the beginning of the activity and have therefore been left out from Figure 1, which shows the change in pupils' on-task interest within the participating countries.

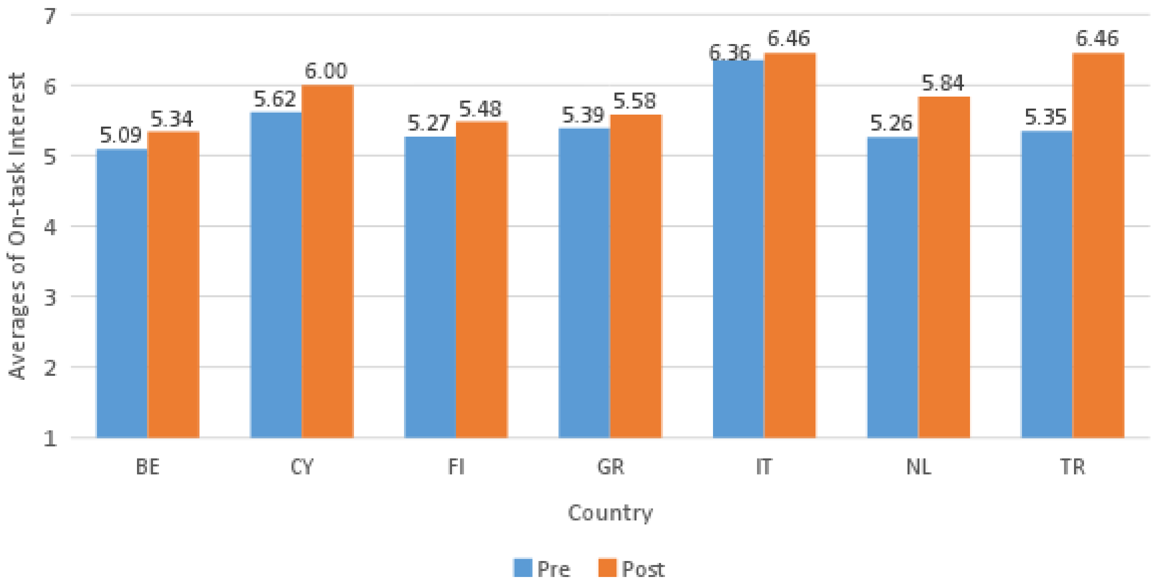

Figure 1. The change in pupils' on-task interest by different countries [14]

In summary, pupils from all the different countries rated their on-task interest quite high both at the beginning and at the end of the activity. The average of pupils' on-task interest increased during the implementation of the inquiry activity in all participating countries as can be seen in Figure 1 above.

Pupils' on-task interest by different STEM domains

To reach the objective of investigating whether the domain of the inquiry activity had an influence on pupils' on-task interest, the data were also analysed by dividing the implemented activities according to their domains and by comparing the responses of pupils that had implemented activities of different domains. This analysis was, however, only carried out with the data of pupils that had conducted inquiry activities from the Ark of Inquiry platform, because not all teachers who used a self-designed activity had reported the domain or domains of the activity.

As can be seen from Figure 2, pupils were highly interested in the inquiry activities regardless of the domain. At the beginning, at least one fourth of the pupils expressed a very high interest in the activities of the following domains: *Biology* (34.4%), *Chemistry* (37.9%),

[14] The results are based on paired samples t-tests due to which they only include pupils who responded to both the pre- and the post-test.

Physics (27.3%), and *Mathematics* (30.7%). In addition, pupils found the activities of *Technology & Engineering* almost as interesting, the most frequent rating being a 6 (28.7%). When interpreting the results in more detail, the number of pupils that found the activity interesting (ratings 5–7) varied from 68.3% (*Mathematics*) to 79.4% (*Chemistry*), whereas the amount of ratings expressing disinterest (1–3) varied between 8.0% (*Technology & Engineering*) and 17.3% (*Mathematics*).

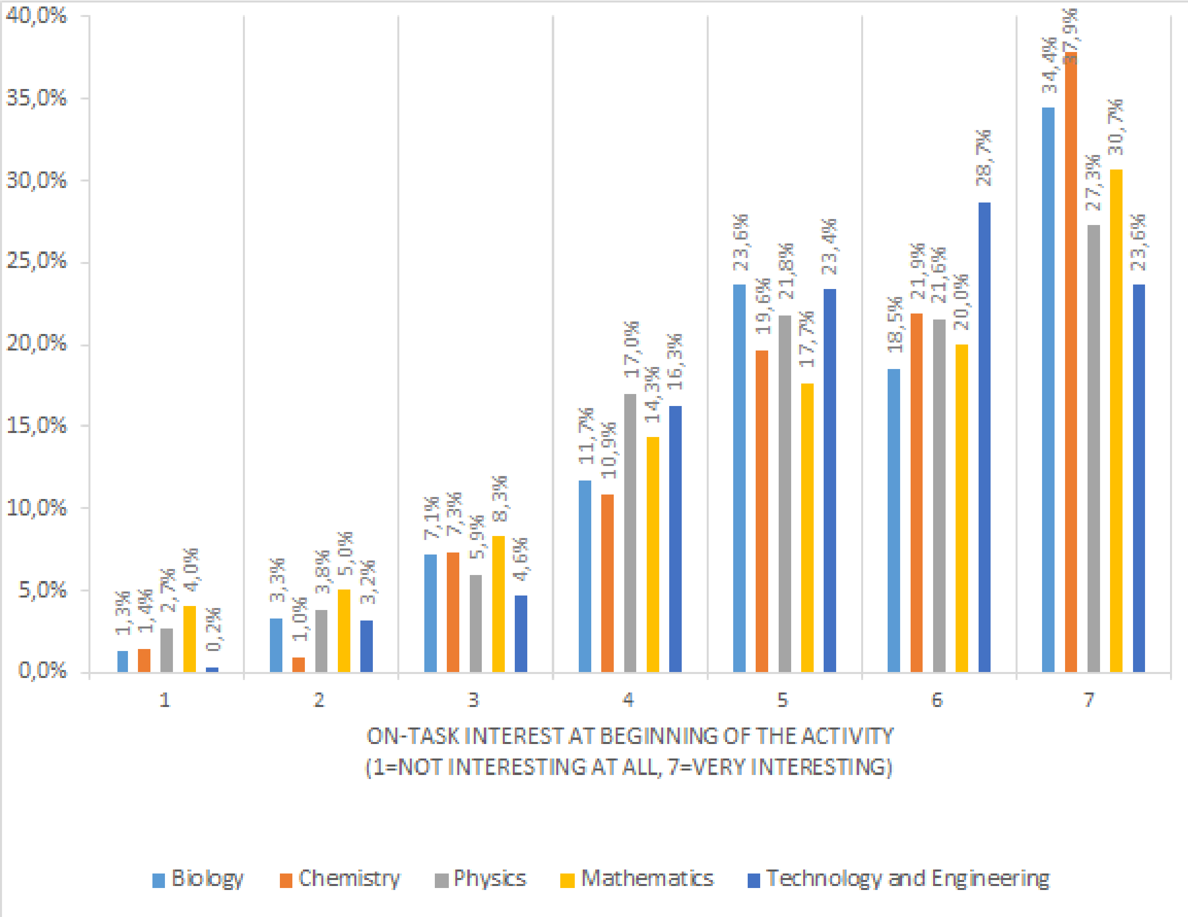

Figure 2. Interest in inquiry learning across different domains at the beginning of the activity

When pupils rated their interest in inquiry learning at the end of the activity, the amount of ratings expressing very high interest was over one third in every domain: from 33.8% (*Technology & Engineering*) to 53.2% (*Biology*). The pupils who found activities interesting (ratings 5–7) varied between 77.4% (*Mathematics*) and 91.0% (*Chemistry*), whereas ratings expressing disinterest (1–3) were reported only in 3.7% (*Chemistry*) to 12.6% (*Mathematics*) of the cases. Details on pupils' interest in inquiry activities of different domains at the post-test are presented in Figure 3.

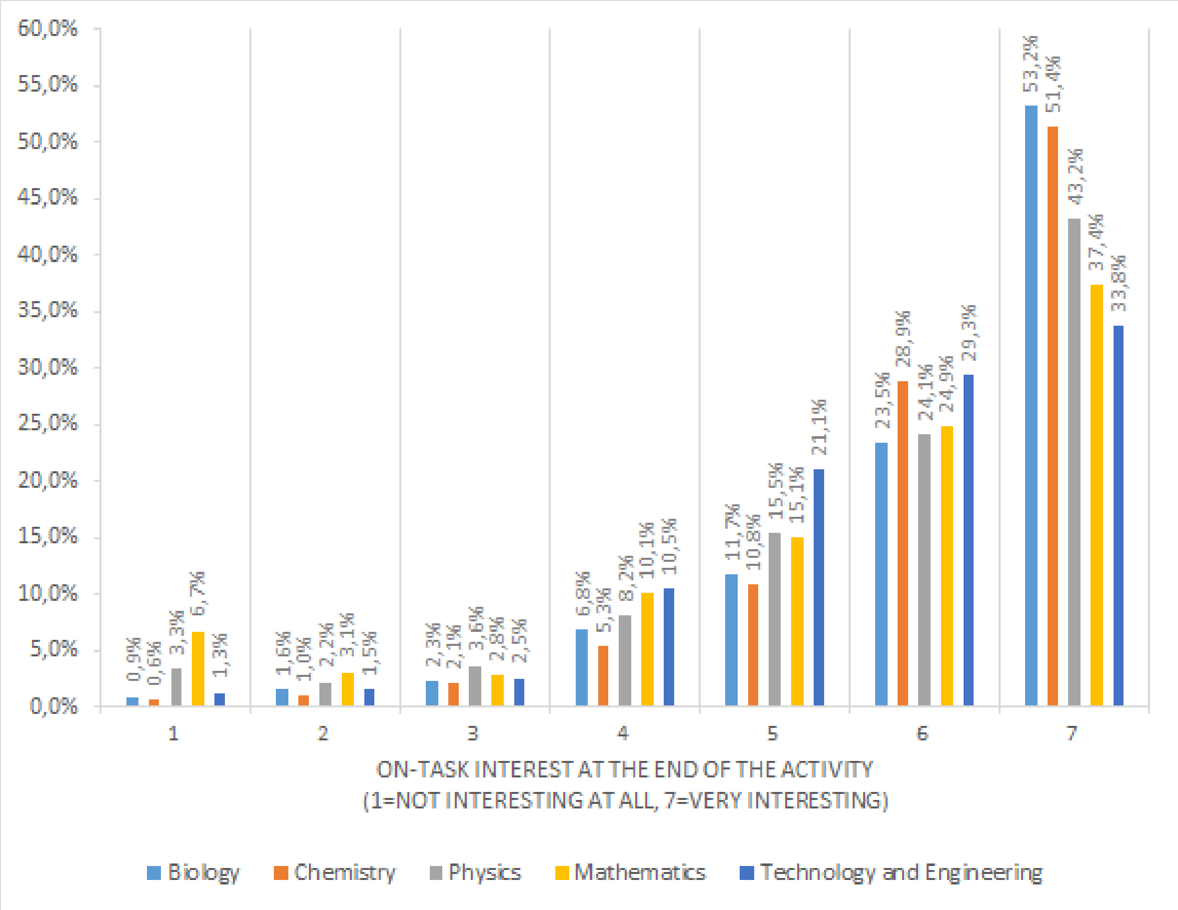

Figure 3. Interest in inquiry learning across different domains at the end of the activity

According to the frequency analysis, most of the pupils participating in inquiry activities tend to find them interesting despite the domain, and the activities were seldom reported as uninteresting. From the perspective of the analysed domains, activities that include mathematics are rated as uninteresting most often by pupils. Therefore, in the future, particular emphasis should be put on designing inquiry activities for mathematics in order to make them more interesting. It is worth noting that many of the inquiry activities included in the Ark of Inquiry platform are multidisciplinary, and, therefore, they often include contents of more than only one domain. This was also taken into account while conducting the analyses, as the activity was included in all the domain groups mentioned in the activity description in the Ark of Inquiry platform.

7.4. Practical relevance

The main objective of this study was to investigate the level of pupils' on-task interest in inquiry activities at the beginning of an inquiry activity session and at the end of the last inquiry activity session. We were also interested in determining whether pupils' on-task interest differed for boys and girls and between younger (ages 7 to 12) and older pupils (ages 13 to 18). Moreover, we analysed the data by countries to be able to provide information about pupils' on-task interest across different Ark of Inquiry partner countries, and, finally, we compared pupils' on-task interest from the perspectives of different domains to find out whether there are subjects that pupils tend to express less interest in.

On the grounds of the results gained from this study, it seems that pupils are highly interested in inquiry activities in general. The average of pupils' on-task interest, calculated based on the data from the beginning of the first activity session and the data from the end of the last activity session, was 5.55 (SD=1.40) on a scale from one to seven. Moreover, our results indicated that pupils found inquiry learning quite interesting already at the beginning of the first inquiry activity session and that their interest in the activity increased during the implementation, although the reasons for the increase were not investigated in more detail. Inquiry learning can therefore be regarded as having great potential for raising pupils' interest in science and learning activities in general, and hence, it can also be seen as an effective teaching method in the science classroom.

By taking a closer look at the data from the perspectives of pupils' age, gender and country, we found that pupils expressed a high level of on-task interest despite of their background variables. The results were quite encouraging in contrast to the recent concerns of girls' declined interest in science learning (e.g., Rocard et al., 2007; Gokhale, Rabe-Hemp, Woeste, & Machina, 2015). In this study, girls expressed a higher interest in the inquiry activity at the beginning of the activity session, while boys found the inquiry activity slightly less interesting. However, the significant difference between genders disappeared during the implementation, as both genders expressed an increased on-task interest in inquiry learning at the end of the last inquiry activity. This result suggests not only that the attractiveness of STEM-related education can be increased through implementing inquiry activities but also that inquiry learning suits well for gender inclusive science education, as it is also able to diminish the gender gap in terms of interest in STEM education.

A significant difference in pupils' on-task interest was also found between the two age groups, pupils aged 7 to 12 and pupils aged 13 to 18. The younger pupils expressed significantly higher interest in the inquiry activity both at the beginning and at the end of the activity session. The difference between the two age groups did not, however, diminish similarly as between the two genders: therefore, we suggest that teachers should become even more aware of the possibilities of modifying inquiry activities according to their pupils' interests, ability levels, and age. When developing learning resources for inquiry learning in the future, it should be strongly emphasised that instead of only implementing the inquiry activity as described in the activity descriptions, teachers should adapt the teaching resources according to their pupils' needs. Our result is in accordance with previous research according to which younger pupils show more interest in science than older pupils (Ardies, De Maeyer, & Gijbels, 2015; Osborne, Simon, & Collins, 2003; Potvin & Hasni, 2014b), and raising older pupils' interest through inquiry activities therefore remains a challenge for education developers and teachers in the field of science.

Pupils' on-task interest in inquiry activities of different domains was also investigated to determine whether there were domains that pupils expressed less interest in. The results suggest that even though the data was not statistically analysed, there may not be any significant differences between pupils' on-task interest in inquiry activities of different domains. Pupils expressed high interest in the activities despite the domain, and, therefore, inquiry learning can be regarded as suitable for covering topics of different domains and as having potential for offering an interesting way of learning in various school subjects.

To conclude, the results of this study are in general very promising, as they support the presumption that inquiry learning has a positive effect on pupils' interest in STEM education. The results showed the versatility of inquiry learning, as it seemed to apply well to all STEM domains, and it was found highly interesting regardless of the gender, age and country of the pupils.

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