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CONTENTS

Editorial

Welcome to the special issue of the Science Education International. This special issue is devoted to activities and findings associated with the Ark of Inquiry project. Ark of Inquiry (http://www.arkofinquiry.eu/) is a research and development project funded by the European Commission involving 13 project partners from 12 countries. The project aims to raise pupils' awareness of Responsible Research and Innovation (RRI) by promoting an interest in science through inquiry learning.

In the Ark of Inquiry project a platform (http://arkportal.eu/) is developed through which carefully selected inquiry-based activities are made widely available across Europe. The platform brings together inquiry-based learning (IBL) activities, learners and supporters (teachers, university students, researchers, staff of museums and universities). To support teachers, the Ark of Inquiry project provides face-to-face teacher training equipping the teachers with skills of supporting and motivating their pupils in their IBL activities.

The partners of the Ark of Inquiry project have developed a project-specific pedagogical framework and related scenarios to support linking the IBL approach with RRI. The framework has been used in carefully selecting IBL activities for a repository that could be used by teachers in teaching students at ages from 7 to 18. In order to support teachers in adopting IBL, a three-phase training model has been developed and used in teaching more than 1000 teachers. Thus, we can say that teachers are at the core of the Ark of Inquiry project. However, it is often not a simple task to train teachers and to support them in using a complex IBL approach, and even more so when we aim to link it with the RRI approach. Therefore, one of the work packages of the project has been focusing on the evaluation of the project activities. This work package has been led by Emanuele Bardone, to whom I am very thankful for the good work done in coordinating all partners, but especially the core research group consisting of people in Finland, Cyprus, the Netherlands, and Estonia. On a more general level, we would like to thank the European Commission for the support given to the Ark of Inquiry project. All the studies reported in this special issue are conducted in the context of the European project "Ark of Inquiry: Inquiry Awards for Youth over Europe", funded by the European Union (EU) under the Science in Society (SiS) theme of the 7th Framework Programme (Grant Agreement 612252). The articles, however, do not represent the opinion of the EU, and the EU is not responsible for any use that might be made of their content.

In this journal issue we present six articles. All articles focus on teachers, but from different angles. In the first two articles we explain the ideas as to how we planned to change teachers' mindsets. We aim to turn teachers into designers of the learning process by inviting them to select and adapt inquiry activities and evaluation tools according to their own and their pupils' needs. This first article from Bregje de Vries, Ilona Schouwenaars and Harry Stokhof is answering the question of whether teachers make adaptations to the approach and materials of the project and if yes then how and why they do it. The authors collected lesson plans and diaries from 20 primary school teachers in the Netherlands and conducted interviews with them. Their findings demonstrate that teachers are willing and able to follow the five-phase IBL model and RRI approach used in the project as well as the formative evaluation procedure. However, the teachers still need to adapt the materials because of several practical and pedagogical reasons. Therefore, it was concluded that the "teachers as designers" approach is a fruitful one that should be supported in teacher training.

The second article is by Alyssa Filippi and Dipali Agarwal, who are not main contributors in the Ark of Inquiry project but have had an internship at UNESCO, one of the partners in the project consortium. Coming from Canada and India, respectively, some of the ideas of the Ark of Inquiry project have already been disseminated from Europe to America and Asia thanks to them. In their article they focus on factors that may be viewed as barriers to adopting the "teachers as designers" approach. The authors report findings from 14 Italian teachers and 30 Indian educators. In their conclusions, access to technology, misconceptions about women's abilities in STEM fields and the effect of poor pre-service teacher training are identified as the main barriers to adopting the "teachers as designers" approach.

The third and the fourth article discover teachers' readiness for being instructional designers. First, Marios Papaevripidou, Maria Irakleous and Zacharias C. Zacharia describe teachers' Pedagogical Design Capacity and Pedagogical Content Knowledge for IBL after completing a course developed in the context of the Ark of Inquiry project. They also shortly describe the three-phase training model (teachers as learners, teachers as thinkers, teachers as curriculum designers and reflective practitioners) used in the project. This information is important, as it provides the context for several of the following articles.

In the fourth article, Emanuele Bardone, Mirjam Burget, Katrin Saage and Maarja Taaler bring in a new dimension in teachers' adoption of new learning approaches. They offer some insight into how RRI could be implemented in science education. In an ethnographic study with seven Estonian teachers the authors conclude that RRI can be interpreted in science education as a "type of meaningful engagement in and for an inquiry during which the students are given the opportunity to make meaningful decisions in the different inquiry phases and thus be able to take responsibility for the inquiry process".

The last two articles of the special issue focus on the findings from the implementation of the teacher trainings of the Ark of Inquiry project. First, Essi Ahokoski, Miikka Korventausta, Koen Veermans and Tomi Jaakkola report the study of 102 Finnish teachers. First, they divided teachers into three groups according to their self-efficacy. Next, they analysed several measures of these groups at the end of the training and found that the general satisfaction with the training and the utility value of the training were similarly high. In addition, the training was useful for increasing the self-efficacy of the teachers belonging to the group that had exhibited low levels of self-efficacy.

Gerli Silm, Kai Tiitsaar, Margus Pedaste, Zacharias C. Zacharia and Marios Papaevripidou are the authors of the other article on changes shown by the teachers. In this study, data collected from a majority of the project countries was used and more than 400 teachers were involved altogether. In the study, changes in teachers' sense of efficacy and attitudes towards IBL as a result of the Ark of Inquiry in-service training were analysed. The results showed a positive effect of the training on some aspects – on the student engagement subscale of the scale measuring teachers' sense of efficacy and attitudes towards IBL. However, the results also demonstrated that systemic restrictions cannot be removed by a training course.

In conclusion, the six studies show that the Ark of Inquiry pedagogical approach and three-phase teacher training have great potential but the effects should be further clarified in future studies; also, data should be collected from learners who form the main target group of the IBL activities available in the Ark of Inquiry repository.

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ORIGINAL ARTICLE

Turning Teachers into Designers: The Case of the Ark of Inquiry

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ABSTRACT

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 light of 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 if, how and why the 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 afterward. The findings show that teachers appreciate and successfully implement the three core elements of the approach (a five-phase model, formative evaluation, and responsible research and innovation). 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 and classroom management) and pedagogical (e.g., preferring group work and alignment with age and capacities of pupils). From this study, it is concluded that the fidelity of implementation concerning the approach is high, and at the same time, the 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 while leaving the principles of the approach intact.

KEY WORDS: inquiry learning; science education; primary education; teachers as designers; adaptation

INTRODUCTION

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. Furthermore, the Ark of Inquiry has been developed for use in three totally different contexts: Primary education, secondary education and in the home. In addition, teachers who come to use the Ark of Inquiry probably differ in both 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.

In general, teachers have found to be crucial factors in the implementation of any innovation (Brown, 2009; Doyle and Rosemartin, 2012). School reform and sustainable curriculum renewal highly depend on teachers' willingness and capacities 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 answered 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, they have been found to frequently adapt innovations to local insights and needs (Barab and Luehmann, 2003). This raises the question as to whether the 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).

Early impressions of teachers exploring the Ark of Inquiry platform 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 Ark of Inquiry activities and evaluation instruments in such a way that their pupils could work with it in groups. Moreover, teachers who were not familiar with formative assessment sought ways to practice this 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.

THEORETICAL BACKGROUND

Many researchers who have studied the implementation of new curricula have concluded that teachers do not enact curricula strictly according to the designs of the curriculum materials provided. Rogers (2003) describes the process of adoption and implementation as consisting of five phases, running from getting to know the innovation to phases of informed decision-making. Ideally, the outcome of the complex process of implementation is that the first trials of actual implementation in the classroom are enjoyable and successful and lead to sustainable adjustment of the existing curricula. Most importantly, what Rogers has shown is that it is not simply a matter of taking that one step to implement new approaches and/or materials. It starts with getting acquainted with new approaches and materials, feeling inspired and motivated, and deciding to adopt it after having thought through the expected relevance, practicality and consequences of using it. After working with the materials in their own practices, teachers encounter a moment of decision-making again: Now that they have experienced how it works, would they like to adopt or reject the innovation?

Besides being a complex decision-making process in which teachers decide for themselves whether or not to adopt the change, many educational (design) researchers show that teachers do not simply implement materials as designed. If they adopt a curriculum innovation, they most probably adapt the approach and/or materials for local usage. Why is this case? Have designers not sufficiently thought through the innovation? From a theoretical and designer point of view, they probably have. However, from a more practical point of view they have not curriculum innovations often are too general to be ready to use 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. They studied the decision mechanisms of three chemistry teachers in more detail and showed that insight into the teachers' complex systems of individual professional goals helps to interpret if and how they adapt curriculum change. Elsewhere the authors state that educational design efforts could become more effective if we become more aware of "the dimensions and magnitude of the issues teachers face when implementing a change proposal in their classrooms" (Janssen et al., 2015, p. 177). By definition, curriculum innovations and new materials deviate from existing daily practices and put forward new affordances and constraints to existing classroom ecologies (Doyle and Rosemartin, 2012). They need to be adjusted to fit the many and sometimes contrasting issues that teachers face. For instance, teachers need to manage their classrooms and keep it to create a safe learning environment for all pupils. At the same time, they need to work toward learning goals and keep track of all pupils. In this setting, curriculum innovations such as inquiry learning or learning by questioning can be quite challenging, and teachers need to find a new balance, both for themselves and their teachers, between structure and freedom (e.g., Stokhof et al., 2017).

From a broader perspective of curriculum development, what happens if teachers adapt curriculum approaches and materials to their own needs and practices? Curriculum development can be described from three perspectives: The intended curriculum, the implemented curriculum and the attained curriculum (Van den Akker, 2003). The intended curriculum can be defined by the design, both its underlying vision/approach as well as its concrete materials. The implemented curriculum comprises the interpretation of end users of the design (the perceived curriculum) as well as the curriculum in action in the actual classrooms (the enacted curriculum). Finally, the attained curriculum is defined by the learner outcomes both in terms of processes and products (the realized curriculum). When teachers adapt curriculum approaches and/or its materials, changes take place between the intended curriculum and the enacted curriculum: The curriculum is enacted in a different way to that set out in the intended curriculum, either because the teacher perceives the intended curriculum as different or because the teacher has good reasons to adapt the intended curriculum. As Remillard (2005) explains, teachers relate to the intended curriculum as active agents who interpret the intended curriculum and become the designers of the enacted curriculum. Similarly, Doyle and Rosemartin (2012) further investigated the gap between intended curricula and the fidelity of implementation in teachers' enactments and conclude that simply viewing it either as the teachers being obstacles to successful implementation or as an expression of great professional autonomy is too simple. In search of a better understanding of the gap between intended and enacted design, they conclude that teachers work in 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 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 accommodate 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 and Luehmann, 2003; Davis et al., 2011).

If teachers act, or should act, as designers of enacted curricula, how could design and implementation best be addressed to assign them this role? A first possibility that has been mentioned in the literature is participatory design which includes teachers (and sometimes even students) from an early moment in the design process. The benefits of participatory design include improvement of the quality and usability of the designs in daily school practices, broad acceptance and adoption of the innovation and better facilitation of its effective use (Janssen et al., 2017). Furthermore, it is argued that (collaborative) participatory design is beneficial for the professional development of the teachers because designing promotes explication of tacit knowledge, reflection in and on action and professional dialog between colleagues (e.g., Carlgren, 2011; Voogt et al., 2011). Participatory design entails a conceptualization of the design process as a social activity inviting multiple perspectives on the design problem and design place. As Richter and Allert (2017) put it, designing involves "critical engagement" of different stakeholders. Rather than designing products, it is about designing and articulating (new) processes of learning.

In addition to opening up the process of designing and inviting teachers to participate, researchers state that the products that come from designing should be flexible and adaptable. When are curriculum materials flexible by nature? Brown (2009) argues that so-called adaptive instructional materials (AIM) have the following three characteristics. First, they consist of building blocks rather than one line of reasoning and usage, and more than one procedure is provided to guide the alignment of the building blocks. Second, the building blocks consist of reusable resources that actively support customization. And third, the materials are easily accessible in different ways so that teachers with varying degrees of motivation and prior knowledge can access the materials in suitable manners. The three characteristics taken together optimally support different modes of use by "being sufficiently open-ended to accommodate flexible use, yet sufficiently constrained to provide coherence and meaning with respect to its intended uses (Brown, 2009, p. 32)."

Finally, adaptive use of new curriculum materials could be supported by dissemination activities and professional development activities that are supportive of teaching as designing. It could be argued that dissemination activities should be widespread to enlarge the accessibility of materials across many different teachers and educational settings. This may be expected to promote dialog about the possibilities and impediments of the approach and materials of the curriculum innovations. At the same time, the curriculum innovation should not be top-down and forced on teachers. In general, it has been found that top-down curriculum renewal mainly addresses teachers' functional development in which teachers' knowledge and skills are trained. Evans (2008) argues that professional training will only be successful if it is aimed at teachers' attitudinal development so that teachers start to experience a need to change first (cf. Van Veen et al., 2010). Besides addressing both attitudinal as well as functional issues related to the innovation, Brown (2009) states that teachers need to develop pedagogical design capacity: "A teacher's capacity to perceive and mobilize existing resources to craft instructional episodes" (p. 29). More than just having the technical skills to redesign materials, by pedagogical design capacity Brown seems to refer to the capacity to perceive and understand theoretical underpinnings and affordances of curriculum designs and having the attitude and capacity to follow them through and turn them into feasible lesson plans.

Returning specifically to IBSE, researchers have created a foundation of flexible design products that allow teachers to make adaptations to local needs and circumstances. In a special issue of science education on building sustainable science education, several contributions emphasize the importance of viewing teachers as redesigners of flexible science curricula. For instance, Squire et al. (2003) described how four teachers implement science projects and point out the influence of local school and classroom cultures on the implementation. They conclude that rather than viewing teachers as assimilating ready-to-use materials, teachers draw on and adapt materials in ways that they view as useful. Likewise, Linn et al. (2003) share their experiences with a web-based inquiry science environment, that supports local customization by design teams as a fruitful means to help teachers build sustainable science instruction. The environment comprises reusable resources that provide building blocks for design teams that build new projects with it and contains characteristics which Brown (2009) notes are effective for the support of the adaptive use of instructional materials. Based on their experiences the authors argue that "sustainable curricular innovations require extensive opportunities for customization and flexible adaptive designs" (p. 517). As the editors of the special issue, Barab and Luehmann (2003) conclude that "the core challenge facing each of these projects is not to design some "correct" version of curricula or assessment that will be implemented "whole cloth" by willing teachers, but to develop flexible support structures that facilitate local adaptation and ownership of each curriculum" (p. 456).

To summarize, implementation is a complex process consisting of several phases. During the process of implementation, 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. To support teachers in becoming designers, based on research on the development and implementation of innovative (science) education we have argued that (1) ideally, teachers participate in the process of designing the innovations (participatory design), (2) curriculum materials are designed to be flexible and adaptive (flexible design products), and (3) professional development should be actively aimed at supporting and facilitating teachers as designers. We have provided several examples of science learning environments that have successfully promoted teaching as designing. Similar to those environments, the aim of the Ark of Inquiry is to promote IBSE in many different contexts. It is expected that teachers who start using the Ark of Inquiry platform will be in need to (re)design its general approach and materials to align them to local needs, preferences, and circumstances. The approach of the Ark of Inquiry is viewed to consist of three main elements: A five-phase model of scientific inquiry, formative assessment of inquiry proficiency, and a focus on responsible research and innovation (RRI). The materials provided include inquiry activities, a toolbox containing formative assessment instruments, and a pedagogical scenario that promotes and guides the design of local RRI activities. In this paper, 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. In the remainder of this paper, we first describe the way the teachers were trained and supported to implement the Ark of Inquiry approach (Method). Next, we present the main results from several case studies shedding light on if, how, and why teachers adapted the Ark of Inquiry approach and/or materials. We illustrate their decisions with examples from the teachers' classrooms. Finally, we conclude by drawing some theoretical and practical implications concerning the design and implementation of the Ark of Inquiry platform.

METHOD

Ark of Inquiry Approach and Materials

The study presented is part of a series of design cycles in which the Ark of Inquiry platform was developed and tested for its relevance and practicality in primary and secondary schools. The Ark of Inquiry platform comprises a theory-based approach containing three elements: A five-phase model of scientific inquiry, a formative approach toward assessment, and a focus on RRI. The elements have been translated to concrete materials for teachers. Table 1 summarizes an overview of the elements and corresponding materials of the Ark of Inquiry platform.

The first element, the five-phase model, was derived from a literature review conducted by Pedaste et al. (2015) in which they identified five phases in inquiry learning: Orientation, Conceptualization, Investigation, Conclusion, and Discussion. The five-phase model represents inductive and deductive routings common in scientific inquiry. The model was used in the Ark of Inquiry platform to produce schematized descriptions of inquiry activities (Siiman and De Vries, 2015). The starting point of the Ark of Inquiry is that pupils work on inquiry activities individually.

Table 1: Approach and materials of the Ark of Inquiry platform

Elements of the approach	Materials for teachers and pupils
Five phase model of scientific inquiry	Schematized inquiry activities
Formative evaluation	Framework of inquiry proficiency
	Evaluation toolbox
Focus on RRI	Pedagogical scenario

The second element of the Ark of Inquiry approach is called formative evaluation and represents the idea that learning to do inquiry demands doing it yourself and developing the (meta-) cognitive awareness to grow from structured inquiry procedures toward more ill-structured problem-solving. Informative assessment, the learner becomes an active participant in assessing learning processes and outcomes and develops self-regulative ways of monitoring and discussing his or her progress with the teacher (Kippers et al., 2016). In the Ark of Inquiry platform, the approach was translated into a detailed framework of inquiry proficiency describing subskills in every phase of inquiry and at three different levels of proficiency: A, B, and C level. A level proficiency concerns the ability to follow a strict procedure with prescribed small steps leading pupils through the phases of inquiry. A typical example of an A level inquiry activity would be conducting a simple experiment with a limited set of variables to find the answer to a given question by collecting and analyzing data in prescribed ways. At levels B and C the inquiry involves more complex and ill-structured problems. To solve those, pupils pose their own research questions and hypotheses, collect and analyze data on complex sets of variables, and take on more responsibility to explain and discuss findings. At B level, which could typically be called guided discovery, pupils are supported in some phases by teachers and/or materials for instance through giving problem descriptions, data collection instruments or presentation formats. At C level, however, pupils guide and monitor their own inquiry processes individually or in groups. Increasingly, pupils need critical reflection, creative skills and the ability to cocreate to discover solutions to open-ended and sometimes multidisciplinary problem statements as typically found in engineering problems.

In addition to this framework of inquiry proficiency, formative evaluation was translated into concrete evaluation instruments gathered in an evaluation toolbox for teachers and pupils (De Vries, 2015). The toolbox consisted of three basic formative evaluation instruments: (1) A protocol for formative dialog between teacher and pupils, (2) a self-evaluation form, and (3) a peer feedback form. The instruments were short and structured with closed and open answer questions that evaluated both the process and the performances of the pupils. The self-evaluation form was provided at two levels: At the A level, the process of inquiry was evaluated by asking what pupils did, what went well, and what kind of support they think they might need in the future; whereas the form a B/C level explicitly refers to the five phases of inquiry and evaluates each phase separately. The self-evaluation forms thus align with an increased awareness of pupils of the process of doing inquiry in phases. Similarly, the dialog protocol supports teachers and pupils to address the five phases of inquiry, thereby raising the awareness of their existence. The three tools are presented as prototypes of the basic forms of formative dialog: Dialog, self-assessment, and peer feedback that can be adjusted according to local wishes.

Finally, the third element of the Ark of Inquiry approach is a special focus on RRI. In the context of the Ark of Inquiry RRI is defined as "the attitude and ability to reflect on, communicate and discuss processes and outcomes of inquiry in terms of its relevance, consequences and ethics for oneself, others, and society" (De Vries, 2015). In this definition reflection is dedicated to thinking through the relevance, consequences and ethics of inquiry, communication refers to the attitude and ability to present and explain the relevance, consequences and ethics of inquiry to an audience, and the act of discussion refers to being able to question the relevance, consequences and ethics of processes, and outcomes of inquiry with an audience. The Ark of Inquiry helps teachers to focus on RRI by providing a pedagogical scenario that explains to teachers how they can design and implement RRI activities in their classrooms. Using the scenario, teachers are supported to design RRI activities in the orientation and discussion phases of an inquiry activity. First, this leads them to relate the inquiry activity to one or several "grand challenges of society" that RRI policy seeks to address, such as health and well-being, climate and sustainability, and technology in society (cf. Groves, 2017). Second, it stimulates metacognitive awareness of scientific inquiry.

The Ark of Inquiry platform was tested in several cycles of usage by teachers in which the relevance and usability of the materials were piloted. A paper walkthrough and small-scale pilots in several countries revealed teachers' perceived relevance and usability and showed that teachers found the framework of inquiry proficiency and evaluation toolbox highly relevant. Teachers also favored the RRI focus and expect it to help them make science more meaningful for their pupils. Teachers also perceived the usability in their classrooms positively, but at the same time already showed their motivation to make local adjustments to the activities and instruments provided. The piloting led to the conclusion that the instruments could best be seen as examples of categories collected in a toolbox to be extended and changed by teachers in the future (De Vries, 2016). Hence, the first trials of the Ark of Inquiry materials brought to light teachers' need for adaptation. The outcomes of the pilots were used to prepare the Ark of Inquiry platform for optimal adaptability. In the implementation study presented here, the adaptability of the Ark of Inquiry platform is explored and evaluated on a larger scale.

Participants

In total, 25 teachers from 19 primary schools located in the northwest of the Netherlands participated in this study. 16 teachers worked at different schools residing under the same board. Nine teachers came from two teams of schools located in the same neighborhood and all teachers volunteered to participate. The majority of teachers were female (n=23), and only two were male, which represents the fact that in the Netherlands primary school teams are predominantly female nowadays. In total, over 500 pupils were represented by the teachers, who worked in Kindergarten (n=6), lower (n=12), and upper grades (n=7), pupils' age ranging from 4 up to 12 years old. Note that the Ark of Inquiry platform has a target audience starting at the age of six, while six teachers worked with younger pupils in the age of 4–6 years old.

All teachers had some experience with IBSE. 16 teachers were trained in the previous years to become science education specialists in their schools. They can be considered experienced users and designers of science education and inquiry learning and have been assigned a task and responsibility by the board for bringing their growing expertise to their colleagues in their schools and invite them to do IBSE in their classrooms as well. Nine teachers can be considered moderately experienced with IBSE. Although most teachers could be considered (moderately to highly) experienced in science education, formative evaluation of inquiry proficiency and RRI were new elements for almost all of the teachers.

Procedure

The participants took part in an initial training, then implemented at least one inquiry activity in their classrooms, and after that attended a second meeting to reflect on their experiences 4 weeks later. The training sessions took place from April to June 2017. The content of the training was derived from training materials provided by the Ark of Inquiry and tailored to the needs of the specific groups. In general, the Ark of Inquiry teacher training contains three building blocks. The first part of the training is aimed at teachers experiencing and learning about IBSE (teacher as learner). The second part aims at learning to implement IBSE and the Ark of Inquiry approach (teacher as thinker), and the third part at (re)designing IBSE (teacher as reflective practitioner). Elsewhere in this issue, a description of the rationale and setup of the teacher training can be found (Papaevripidou, Irakleous & Zacharia, 2017). Because the teachers were experienced in doing IBSE in their classrooms, the training focused on turning teachers into designers: The second and third parts were put central and teachers were invited and triggered to translate Ark of Inquiry elements and materials into lesson plans for their own classrooms.

The first training session focused on letting teachers prepare the implementation of an inquiry activity in their classrooms that contained or revealed the five-phase model, formative assessment and RRI. Ark activities were provided, and some teachers brought their own activity or started designing one during the training session. Introductions to the Ark of Inquiry approach and materials were given to the five-phase model, the evaluation toolbox and the RRI scenario after which teachers worked on their lesson plans. The first meeting took 4 h. The second session took place after 4–6 weeks and focused on listening to and reflecting on each other's experiences. This second meeting took the form of a reflective dialog with subgroups of teachers. The teachers provided input to talk about by handing in their designs and diaries. A semi-structured interview protocol was used to structure the conversation. The second meeting took one up to two and a half hours depending on the number of teachers present. The total duration of the training was 5–8 h.

Data Collection and Analysis

To gain insight in teachers' choices and reasons for adoption and adaptation, the following data were collected. First, during both training sessions, informal field notes were taken on the reactions teachers gave to the introductions and while working on their lesson plans. The teachers' reactions and questions were taken into the background of data analysis. Next, teachers were asked to keep diaries on their decisions during designing and implementing the inquiry activity. In the first part of the diary, the teachers were asked to describe and explain their design decisions on the level of the activity, which phases were present in the activity and if they wanted to emphasize certain phases over others. Furthermore, the teachers were asked to describe and explain their choices related to RRI and evaluation of inquiry proficiency and to describe the time schedule of the lesson. In the second part of the diary, the teachers were asked to reflect on the implementation of the lesson. In this part, the teachers answered open questions about their general impression of the lesson, and their appreciations of the RRI activity, and formative evaluation. Furthermore, the teachers were asked to draw conclusions if and how they would repeat the lesson in similar or different ways. The collected diaries contained 10 pages of questions and open spaces for adding written answers. The diaries could be filled in by the teachers digitally or on paper. Two teachers handed it in digitally, all other diaries were collected on paper. In total, 25 diaries were collected. The diaries recorded the teachers' global reflections on the design as well as implementation and were viewed to be the trigger for more detailed data collection during interviews.

Third, all teachers but one took part in group interviews after they implemented the inquiry activity in their classrooms. Seven group interviews were held, the seventh interview with one teacher only. The interviews took half an hour up to two and a half hours depending on the number of teachers present. In total, 332 min of audio recordings were collected. During the interviews, a protocol was used that asked the teachers to reflect on their lessons in general (and their pupils' feelings about it), on the formative evaluation they enacted, and the RRI activity they had implemented. The teachers took turns in their group; all reported their experiences and follow-up questions and remarks were shared by both the interviewer and the other teachers. The interview questions asked them about the choices they made, how they worked out in practice, if and how the training and materials had supported them or not and their thoughts for the future. After the semi-structured interviews, the diaries and lesson plans were collected. Some teachers brought products of pupils as well, and these products were collected to enrich the background of data analysis.

Data analysis was conducted in several steps. First, the lesson plans and materials were described in terms of their subject and (estimated) inquiry level and categorized according to their origin (Ark activity, designed by teacher, and another source). If it was an activity provided by the Ark or another source, it was described if and what adaptations teachers had made for which the spider web of curriculum design (Van den Akker, 2003) was used as a framework. In this spider web, nine aspects of a lesson plan are addressed: Learning goals, content, activities, role of teacher, materials used, grouping, time/duration, location, and assessment. To summarize, the (re) designing that teachers did we scored which elements teachers adapted. The first step in the analysis procedure was to get an overview of the kind of inquiry activities the teachers used in their classrooms and to gain first insight in the kind and amount of adaptations they made to existing activities.

Next, the teachers' diaries were read and an overview of their reflections on (re)designing and implementation was made by assembling statements on either (1) inquiry learning in general and the inquiry activity specifically, (2) formative evaluation of inquiry proficiency and concrete materials of the toolbox, or (3) RRI and the pedagogical scenario. The overview of statements from the diaries gives first impressions of their reasons to adapt or not and how they appreciate and/or experience the possibilities to make adaptations. Statements consisted of answers to the open questions from the format and were in varying lengths ranging from short paragraphs of several sentences up to a few pages. Teachers' responses differed, as sometimes they provided only short answers for one question but, for other questions, would respond at some length. Occasionally, teachers added additional notes and lesson materials taken from the teachers' preparations to illustrate design decisions in more detail. The most lengthy statements were produced where the teachers described and explained the activity phases and RRI activities. Statements on the design and implementation of evaluation instruments were found to be shorter, often containing only a few words or sentences.

Finally, the group interviews were transcribed and analyzed by categorizing what teachers said into statements about the three elements (inquiry, evaluation, and RRI) and materials. The transcriptions of the seven interviews in total covered 46 pages and 25.465 words. Data analysis was conducted top-down by categorizing the statements according to the three elements of the Ark of Inquiry approach. Next, a closer look on the statements within the same element led to grouping similar statements in subtopics, such as "phases of inquiry," "inquiry proficiency," "capabilities of pupils," or "authenticity." This way, summaries of the elements emerged that tried to capture both general as well as specific observations made by the teachers.

Findings

This section contains two parts. First, general impressions of the inquiry activities that the teachers designed and implemented are described. A summary of types and characteristics of the activities is given, and several aspects of the designs are mentioned using the curricular spider web as a framework (Van den Akker, 2003). In the second part, a closer look at the teachers' designs in light of the three elements of the Ark of Inquiry is taken: How do the designs relate to the five-phase model, formative evaluation, and RRI.

Overview of Activities Designed

Three sorts of activities were realized: Engineering activities, experimenting, and guided discovery. Engineering activities were aimed at letting pupils design, build and evaluate a construction. Examples of engineering activities are 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 C level. 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 A level 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 Egg in a bottle and Floating experiments, taken from the Ark platform and a science education syllabus, respectively. The guided discovery activities, finally, took the form of a series of lessons or project in which teachers pre-structured the discovery process of their pupils in loose ways 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 the Kindergarten and lower grades. In the Netherlands, pupils and teachers in lower grades are very much used to learn by playing and hands-on discovery. At the same time, the pupils are that young of an age that they need guidance and surveillance by their teachers as well. Furthermore, guided discovery was characterized by open goal settings and often moved along by pupils own questions that spontaneously popped up after being introduced to the general topic. In contrast, engineering and experimenting have set goals from the beginning. Table 2 summarizes an overview of types of activities and main characteristics found in the dataset.

In several engineering projects, the teachers used experimenting as a way to introduce the topic. In the orientation phase, an A level activity was used whereas in the following phases an ill-structured design problem was put central. Similarly, several experimenting activities ended with an open discussion on its implications, posing follow-up questions and creative reflection on the outcomes of the experiment. In their diaries, this was reflected by the teachers documenting the discussion phase as a C level task. From the overview of designs and reflective reports of the teachers it becomes apparent that although an activity could be scaled at one level mainly, subtasks are often included which levels differ from the overall level. The teachers were aware of level differences and applied level allocation per phase.

Moreover, some teachers reflected in their diaries on what pupils actually did while performing the activity and sometimes recognized an uncharacteristic behavior for the level of activity. 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 that 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.

To gain more fine-grained impressions of what teachers designed or adapted, the overview of activities was analyzed additionally from the perspective of curriculum design as described by Van den Akker's spider web (Van den Akker, 2003). As already described, the spider web discerns nine aspects (learning goals, learning content, learning activities, role of teacher, sources and materials, grouping, time/duration, location, and assessment) that need to be designed in accordance with each other to get sound lesson plans. From the designs of the teachers, it follows that the teachers interpreted and/or adapted the Ark of Inquiry approach in important ways related to five aspects of the spider web. Concerning the aspect of grouping, they often changed the mainly individual focus of the Ark of Inquiry into a collaborative focus by organizing group work rather than individual inquiry. Across the three types of activities and five phases of the inquiry model, pupils frequently collaborated in whole class settings as well as small groups. In their diaries and interviews, many teachers emphasized that they view doing inquiry with pupils as essentially social and they designed or adapted the inquiry settings accordingly. Concerning the aspect of sources and materials, in case of using existing activities, the teachers added additional materials designed by themselves or collected from websites or methods. For instance, they designed worksheets with which their pupils could address important questions while doing experiments. By doing so, they increasingly structured the activity and in fact changed the level from B/C to A, of which most teachers were aware. 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. In one case the teacher started with the A level activity Egg in a bottle in the orientation phase, and

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, 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

after the orientation phase put the pupils to work with the open-ended engineering problem of building chicken coops that are animal-friendly. In another classroom the pupils started with cutting and pasting parts of a dinosaur skeleton, which was rated as a B level activity, and after finishing that further explored the topic by posing their own questions and formulating hypotheses about the living environments of dinosaurs combining new information on history, geography, and biology in an open learning environment. Although the teachers were aware of the fact that they adjusted the structure of the activities and turned them into more or less structured problem domains, the teachers did not refer explicitly to this as changing the level of proficiency.

Concerning the aspects of learning goals and content, and related to that assessment, it was observed that although the Ark of Inquiry aims at developing inquiry proficiency by raising awareness of and developing skills to become basic or advanced researchers, the teachers hardly ever defined learning goals related to inquiry proficiency. This is not to say that inquiry proficiency did not become part of the learning content, but in their designs, the teachers did not state this explicitly. This raises the question if the pupils were aware of learning goals related to inquiry proficiency. Mostly, learning goals related to the domain and subject were made explicit and addressed in the orientation and discussion phase. In the engineering activities, for instance, design products were tested and discussed. Only incidentally did some teachers pay attention to inquiry skills as learning goals in the beginning or end of the activity. Reflection on the process of doing inquiry was only addressed globally by asking pupils what went well or could be improved. One skill relatively often mentioned by teachers was "how to formulate a research question and hypothesis." Other skills related to inquiry proficiency that was paid attention to regularly was "looking up information in books and websites" and "working in groups." Several teachers indicated in their diaries and interviews that pupils find it difficult to reflect on their learning processes. As one teacher put it: "My pupils still need to learn to observe themselves as learners and ask questions" (teacher Grade 4). Similarly, another teacher 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 easy 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 cannot explain in more detail what they liked most" (teacher Grade 3).

Adaptations to Approach and Materials

Most teachers in this study designed their own inquiry activity. They did not so much adapt activity materials present in the Ark but chose to design new ones. Five teachers used existing materials either coming from the Ark or another source. How do both groups of teachers relate to the three elements of the Ark of Inquiry approach: The five-phase model of scientific inquiry, formative evaluation, and RRI? Do they use any materials provided by the Ark, such as the formative evaluation instruments?

The teachers who designed new materials (n=20) used the five-phase model to structure the activity as can be seen in the design products and lesson plans. They used the model to define parts of the lesson, as well as to put focus on one or several phases if needed. They not only used the logic and order of the phases but also the wordings, for instance: "I always try to do an introduction, what do we already know about something, collecting examples. Often I show them a nice short movie from YouTube. Hence, we do an orientation phase that way" (teacher Grade 5). At the same time, some teachers reflected on the model by explaining they already knew the phases from other models using different terminology. They used the phases of the model without explicitly using the wordings. As one teacher 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" (teacher Grade 7). Some teachers explained that the five-phase model helped them to pay increased attention to specific parts of the inquiry process, for instance by designing more extended orientation and discussing phases that help to round up the inquiry than they used to. Several teachers explained in their diaries and interviews how the model helped them to take time for orientation and discussion: "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 in 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" (teacher Grade 7). Another teacher explained an increased function of the orientation phase: "We spent quite some time on 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" (teacher Kindergarten).

For all but one teacher, formative assessment in the context of IBSE was new. 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 teacher-pupil dialog, 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 indeed started using formative evaluation tools in their classrooms. Furthermore, the data show that the teachers redesigned the basic forms of the toolbox into adapted instruments and ways of usage. Table 3 summarizes an overview of methods/instruments used by the teachers.

Three teachers did not implement formative assessment. The other teachers implemented at least one and sometimes a combination of evaluation tools. As can be seen in Table 3, the teachers made many adaptations to the original tools by adapting the formats and/or the way they were used (timing and setting). Several important observations can be made in the data. First, many teachers performed formative dialog, but no teacher used a protocol to structure the conversation. The dialog mainly had the character of an open conversation, either with the whole class, in smaller groups or with one pupil. 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. In addition, peer feedback forms were often replaced by oral conversations in which peers gave each other feedback in the form of tips and reflections on products of peers. And third, many teachers aimed the evaluation activity to the content of the activity rather than the inquiry process. As a consequence, the feedback often concerned the quality of a product or presentation rather than the inquiry proficiency. Although both peer feedback and self-evaluation were experienced as rich and fruitful ways of making pupils more aware of their own experiences, skills and remaining questions, the evaluations were often aimed at domain-related content rather than inquiry proficiency. This finding suggests that teachers not only adapted the evaluation materials provided by the Ark but also more profoundly its approach that focused on the evaluation of inquiry proficiency. Most teachers indeed expressed in their diaries and/or the interviews that they find it difficult to evaluate inquiry processes with their pupils. However, there also seems to be a lack of awareness with the teachers themselves who frequently report on the evaluation of learning content rather than learning processes in their diaries.

How did the teachers relate to RRI? Half of the teachers realized an RRI related activity or discussion addressing grand theme related issues such as "why is doing brain research important," "pollution of the sea," "what are good ways of keeping animals in cages," and "who can benefit from research on muscle diseases." 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. In the interviews, the teachers explained in more detail that 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 found are 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, discussing the ethics of working with animals and discussing the fact that experiments can also fail. The RRI topics were mostly aimed at societal challenges and themes. The extent to which the teachers introduced discussions around awareness of the process of doing inquiry was far less. In only a few interviews did the teachers express the spontaneous occurrence of questions about ways of doing research and effects of doing research as a topic that was discussed with the pupils. Sometimes the RRI activity was used to raise metacognitive awareness of the processes, pitfalls and merits of scientific inquiry, but this was rare.

Taken together the cases do show if and how RRI can be addressed by exploring or discussing small topics derived from grand challenges with even 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 be 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. Hence, 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

Table 3: Enacted curriculum: Method and instruments of formative evaluation

Method of evaluation	Instruments	Examples of usage
Formative dialog (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	Photo with explanation/reflection
	Form from another method	Statements with Likert scales
		Making it part of portfolio
		Computer-based administration
Peer feedback (n=9)	Open conversation	Tips and tops
	Oral presentations	Discussing designs
	Object presentations	Small group conversations
	Adapted peer feedback form	

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, about half of the teachers expressed difficulties designing and realizing RRI activities in their classrooms for several reasons. Some experienced a 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 designed and implemented an experiment (A level activity). Putting an experiment such as Egg in a bottle in a meaningful context that pupils can discuss was experienced as artificial or too big a step, especially for pupils from lower grades.

CONCLUSION AND DISCUSSION

In this paper, we explored the ways in which teachers in primary schools in the Netherlands use the Ark of Inquiry approach and materials in designing and implementing IBSE in their classrooms. The idea behind the study is that generally teachers are inclined to adapt curriculum innovations to make them fit their own concerns and practices. The aim of the study, therefore, was to find out if teachers, how and for what reasons teachers adapt Ark of Inquiry materials and if the materials were found to be adaptable. Three research questions were explored: (1) What are the most important adaptations teachers make to the Ark of Inquiry approach and materials. (2) Why do teachers make certain adaptations and (3) How do teachers appreciate their roles as designers?

In answer to the first research question the findings suggest that the teachers experience the elements of the approach – the five-phase model, formative evaluation, and RRI – as worthwhile and important. They are motivated to implement the elements into their practices. In that sense, the teachers adopt the core principles of the Ark of Inquiry. Do they also adopt the materials – activities, evaluation tools and RRI scenario - that the Ark provides? We found that many teachers designed their own activities. Inspired by the materials provided they used whatever they could use but at the same time also invented new materials from scratch. That the teachers frequently (re) designed inquiry activities may be explained by the fact that they were experienced designers and users of IBSE who felt confident enough to do so. In the process of designing, the teachers used the five-phase model to structure the activities and hence successfully implemented the five-phase model in the activity and materials used.

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 practices, the teachers adapted the evaluation materials in such way that the focus changed from process-oriented to content-oriented. The learning goals set by the teachers appeared to be mainly focused on domain and subject related content rather than inquiry proficiency skills. The teachers hardly focus explicitly on learning goals related to inquiry proficiency. The formative evaluation instruments that the teachers developed confirm this shift of focus. It is, therefore, 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 relevance, consequences and ethics of research outcomes. Only rarely did the teachers discuss the process of scientific inquiry with their pupils. Half of the teachers find it difficult to realize RRI activities and explained this by time constraints, age of pupils, or nature of the inquiry activity. A level activities were more difficult to embed in RRI activities for the teachers than B/C-level activities.

In answer to the second research question, we found that teachers have several reasons to adapt materials. One reason that was frequently mentioned was to tailor materials to their pupils needs, for instance increasing the suitability for pupils in lower grades or gifted pupils. A second reason that was mentioned to align the materials to existing practices and tools present in the schools. Some teachers replaced Ark materials with evaluation tools already available in their schools. Finally, teachers adjusted materials for practical reasons: To save time and/or make them easier to use.

In answer to the third research question, our findings confirm the theoretical evidence that teachers want to adapt new materials according to their own needs. They seem to find it rather natural to do so. This could be explained by the fact that many of the teachers who participated were at least moderately experienced with IBSE, and with designing inquiry activities. Furthermore, the primary school teachers participated in a group culture of sharing materials, of getting inspired by others and using each other's lesson designs. They belonged to the same school team or to a regional group of IBSE experts. In this culture of sharing and reusing they seemed to take it for granted that the materials provided could be adapted. The Ark of Inquiry materials and the way they were introduced in the teacher training turned out to address their expectations sufficiently.

Overviewing the findings our main conclusion is that the Ark of Inquiry successfully invites and supports teachers to realize IBSE in their classrooms in their own preferred ways. This may be explained by relating the Ark of Inquiry materials to the characteristics mentioned by Brown (2009) that make teaching materials optimally adaptive. Ark materials consist of reusable building blocks that could be accessed in multiple ways through the platform (website) as well as through provided snapshots in the training. Hence, teachers could start working with the inquiry activities and evaluation tools more or less structured by following the preselected materials or choose to explore the website and materials more freely themselves. And they could choose to follow the procedures provided or design their own adapted procedures. Furthermore, the resources were open to teachers' own materials and not presented as a closed circuit. Indeed, teachers frequently chose to add own materials collected in their own schools, and they were actively invited to do so during the training sessions. Moreover, the training sessions emphasized the nature of the materials as adaptable building blocks rather than ready-to-use materials and provided many examples that illustrated their adaptive use by other teachers. In short, the teachers were trained to develop their pedagogical design capacity rather than develop the technical skills only needed for inquiry learning and formative assessment. During the training, the building blocks provided by the Ark of Inquiry invited teachers to discuss their ideas about the general approach. For instance, teachers were instigated to compare the five-phase model of scientific inquiry to other models of inquiry they knew. In short, 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 to become designers of their own IBSE projects.

In this article, we have reasoned that the implementation of new curricula in daily practices is always a matter of adoption and adaptation and never a matter of adoption alone. With this case study, we have tried to describe and illustrate the many ways in which teachers think about and take action in realizing IBSE. As such, the study could be seen as an illustration of how teachers move from the intended curriculum consisting of its approach and materials toward a realized curriculum standing for their performance in their classrooms (for an overview of curricula representations, see Van den Akker, 2003). It seems reasonable to conclude that in this process of adopting an intended curriculum through adaptation and implementation to a realized curriculum, some things are gained, and some are lost. In a final attempt to balance the findings described, we conclude that many gains were observed such as the easiness with which the teachers and pupils moved from A level activities to more open problem statements at B and C level. These seemed to be more of a natural environment for them then many more structured A level activities. Likewise, we observed the natural implementation of dialog as the main way to evaluate inquiry outcomes and discuss them, half of the time from creative RRI perspectives. However, we also saw some losses, and the main one may be the lack of focus on inquiry proficiency in both the evaluation and RRI activities. Although all the teachers adopted the idea of formative evaluation of inquiry proficiency in the intended curriculum, they found it hard to implement. Getting back to the curriculum representations found in Van den Akker, further inquiries into teachers' perceived curricula – this is the way they look at and interpret the intended curriculum – might explain for some of the changes. Furthermore, 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.

What else might explain the discrepancy between the adoption of the idea of formative evaluation of inquiry proficiency and successful implementation? An interesting perspective is provided by Smith et al. (2013) who suggest that teachers need so-called 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 the teachers need to help their pupils become aware of the phases and skills involved. It is suggested here that the teachers may lack this PPK related to scientific inquiry and therefore can use the five-phase model (implicitly) in their designs but not yet in their conversations with pupils to stimulate metacognitive awareness. Further research on this might further inform us on how teachers can be supported in the process of adaptation so that core principle of a design is preserved as much as possible.

The educational field is in need of and searching for ways to provide teachers with the know-how and supportive tools to become (re)designers (cf. Janssen et al., 2017). By exploring and evaluating the potential for adaptation of the Ark of Inquiry approach and materials we hope to have contributed to an ever-growing vivid picture of what it means to be a teacher-designer.

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International Council of Association for Science Education

ORIGINAL ARTICLE

Teachers from Instructors to Designers of Inquiry-based Science, Technology, Engineering, and Mathematics Education: How Effective Inquiry-based Science Education Implementation can result in Innovative Teachers and Students

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ABSTRACT

There is a need for individuals in science, technology, engineering, and mathematics (STEM) careers to drive the innovation and research potential of Europe. Yet, there is expected to be a decrease in the number of STEM professionals, as there is less student interest in STEM fields of the study. Studies show that STEM classes that focus on inquiry-based science education (IBSE) are engaging and encourage students to become more fascinated with STEM fields. The Ark of Inquiry Project involves a consortium of STEM- and education-focused universities and organizations across Europe that created an online platform with IBSE and STEM lessons. The UNESCO Regional Bureau for Science and Culture in Europe conducted the pilot phase of the Ark of Inquiry Project in Italy from September 2015 to February 2016. In this paper, we will discuss some of the barriers to the expansion of this online STEM education project that was noted by the 14 participating Italian teachers of the pilot phase and 30 educators from India, Germany, Canada, and Denmark who participated through online surveys. We discovered that teachers must be able to overcome barriers of access to technology, misconceptions about women's abilities in STEM fields, and the effect of poor pre-service teacher training as it relates to implementing IBSE effectively for student-centered learning. This paper will focus on how the above factors hinder the growth of teachers as designers and facilitators of student-centered IBSE curriculum and will recommend how The Ark of Inquiry Project can be scaled up to impact the rest of the world.

KEY WORDS: inquiry-based science education; gender representation; technology; barriers; pre-service teacher training

INTRODUCTION

Student interest in entering postsecondary science, technology, engineering, and mathematics (STEM) fields has declined in Europe, which means that there may be fewer STEM researchers in coming years (OECD, 2007). This decrease in researchers will impact Europe's capacity for quality research in science, technology, and engineering. The OECD-PISA report, 2015, suggests that, "at a time when science literacy is increasingly linked to economic growth and is necessary for finding solutions to complex social and environmental problems, all citizens, not just future scientists and engineers, need to be willing and able to confront science-related dilemmas" (OECD, 2015). This shows that innovation in STEM fields is imperative to the innovation potential of the world as society begins to face complex problems. These problems include the impacts of climate change, food insecurity, and explosive population growth. Therefore, the aim of the Ark of Inquiry: Inquiry awards for youth over Europe project (Ark of Inquiry) is to increase youths' interest in STEM careers by introducing engaging online inquiry-based science education (IBSE) activities at the elementary and high school level, with a focus on responsible research and innovation (RRI).

The Ark of Inquiry Project is based on an online platform. The platform hosts STEM lessons and activities written by members of the Ark of Inquiry Project consortium or lessons acquired from partners or contributing educators. Teachers can search the platform's database to find and use appropriate IBSE activities for their classes.

However, the success of the project will be measured by the sustainability of the Ark of Inquiry online community, and how teachers continually engage with it to design meaningful IBSE learning experiences in their classrooms. Similarly, the project will be called successful if students learn about the inquiry process itself, as well as the STEM content being taught (Deliverable D2.1, 2014).

In this paper, we will primarily discuss the major roadblocks to changing the role of the teacher involved with the Ark of Inquiry Project from "instructor" of STEM content to "designer" of IBSE learning experiences.

From our research, we have observed that the following barriers to project success may include:

1. The inclusion of all students, more importantly girls, in STEM activities, especially when girls face stereotypes about their abilities.
2. The need for consistent and reliable access to technology by students and educators to take part in the online Ark of Inquiry Project. This includes teachers' capacity to use and manipulate new technology, and their potential to access new and relevant technology devices.
3. The lack of robust pre-service teacher training that discusses IBSE or educates teachers on how to effectively teach STEM content to their students in a way driven by real-world application and inquiry.

LITERATURE REVIEW

IBSE and RRI

Achievement studies demonstrate a link between enjoyment of learning science and science achievement. PISA 2006 showed that students' belief in whether they could handle tasks effectively and overcome difficulties was closely related to increased performance in sciences (OECD, 2007a). Research shows that IBSE lessons increase students' understanding and engagement with science (Pedaste et al., 2015). These IBSE activities are also intended to improve youths' inquiry skills, increase their awareness and understanding of conducting "real" science, and prepare them for addressing real-world STEM issues through a critical scientific process.

RRI is a framework that focuses on integrating European values, needs, and expectations into research practices. This framework is best outlined by the European Commission's RRI document: "RRI means that societal actors work together during the whole research and innovation process to better align both the process and its outcomes, with the values, needs, and expectations of European society" (European Commission, 2012). Therefore, students should learn STEM content that is based on real-world application.

Implementing RRI into the Ark of Inquiry activities and teaching includes discussing and debating scientific conclusions from research, which can be seen in the 5 inquiry phases followed by the Ark of Inquiry Project activities in the Appendix A (Pedaste et al., 2015).

Attitudes toward Technology

According to the European Commission on Education and Training, there is an urgent need to boost digital and technology skills and competencies in Europe for the following reasons:

- 37% of the EU workforce was found to have low digital skills or none at all.
- Less than half of children are in highly digitally equipped schools and only 20–25% of them are taught by teachers who are confident in using technology in the classroom.
- Between 50% and 80% of students never use digital textbooks, or any other learning software in the classroom ("Opening up education through new technologies," 2017)

Therefore, the European Commission launched an action plan called "Opening up Education" in 2013. The main aim of this plan is to teach the digital skills to teachers so that they can deliver modern digital-based education. This OpenEdu framework contributes to the achievement of open and innovative education through digital technologies, which is one of the six new priority areas for the education and training 2020 in Europe. By increasing access to technology, young learners may learn more skills and be able to learn in digital spaces ("Action Plan for Education 2017," 2017).

A study on barriers to creativity and innovation across schooling in Europe indicated that tools such as textbooks are still the most utilized teaching resource in a class, closely followed by printed worksheets (Banaji et al., 2013). The authors of this study noted that while using these classroom tools were not barriers to creativity, the refusal of school leadership to go beyond these materials and use digital devices is a barrier to innovative classroom practices.

In addition, Banaji et al. noted that not all technology practices in schools are being implemented well; in some of the EU27 countries, experts reported that not all government or EU programs which require schools to buy interactive whiteboards (i.e., smart boards), laptops, tablets, or learning platform environments succeed in increasing students' technology and digital skills. If teachers do not know how to use the technology, the technology cannot be used effectively for new and innovative education purposes.

Furthermore, Banaji et al. also noted that due to insufficient teacher training, slow internet connections in schools, and a lack of leadership in the effective uptake of technology in schools, many of these technology implementation programs largely failed (2013). The presence of technology does not equate to digital and technological proficiency, just like the presence of a pen does not indicate a student's literacy level.

The researchers state that school administration, teachers, and school boards desire to control students' use of ICT at school. An example of this control is shown through schools' blacklisting of certain websites that the students cannot use as they are deemed "not educational." YouTube is a commonly blocked website because content creators on the platform are very popular with youth today. However, the platform also hosts STEM tutorials and demonstrations. By blocking these websites, students and teachers cannot think creatively about learning new information. The researchers note that these restrictions demonstrate an unwillingness of hierarchical systems in schools to be challenged.

According to a study done by the education foundation, the following key barriers to technology implementation in schools exist:

- Skills
- Access to technology
- Pedagogy
- Value for money, and

- Accountability ("Technology in Education: A System View," 2014).

Basic online skills (to get online and navigate through websites), traditional IT skills (maintenance of IT hardware), computer science skills (understanding principles of information and computation), digital commerce skills, and data science skills are required for students to use ICT in a meaningful way.

There are major issues related to gaining quality access to internet and technology infrastructure in schools. Access can be even more difficult for small schools and schools in rural areas. Schools need to use the right blend of technology and teaching pedagogy to give students meaningful ICT education. Since access to ICT can be expensive and capital-intensive, schools need to look at innovative ways to fund and maintain these technological resources ("Technology in Education: A System View," 2014).

Gender Discrimination

There is ample research which shows that girls can be blocked from learning and participating in STEM classrooms due to stereotypes about their abilities based on gender. This is, especially, important to make note of in the context of this international education project. Different countries have varying social and cultural perceptions of traditional gender roles and can therefore hold prejudices against women pursuing STEM fields (Dweck, 2007).

Dweck describes two theories of intelligence that explains how individuals view themselves as learners (2007). The first theory is the entity theory of intelligence. If a learner holds this view, the learner believes that intelligence and ability are fixed and do not change over time; someone either is intelligent or is not intelligent. Dweck noted that the females she surveyed held this entity theory of intelligence. Therefore, the females in Dweck's study were more vulnerable to losing confidence when faced with academic obstacles than male students (2007). Ultimately, Dweck found that this entity theory of intelligence could dissuade these female students from pursuing STEM fields (2007).

The second theory of intelligence is an incremental theory. If a student holds this view, they believe that intelligence and ability can be acquired through risk-taking, practice, and determination to learn. More males than females held this incremental theory of intelligence (Dweck, 2007). This capacity to take risks and make mistakes while learning is a fundamental part of IBSE during the questioning, experimenting, and investigation stages. Risk taking is also a fundamental behavior associated with academic success, especially relating to technology and mathematics (Ramos and Lambating, 1996). To include girls in STEM learning, Dweck recommends that a teacher should not focus on who has the scientific ability or who does not, but rather on how to foster and develop such abilities in students (2007).

This is also important to note when considering the "leaky pipeline" effect (Blickenstaff, 2005). The phenomenon is called the "leaky pipeline" because there is a disconnect between what the parents, teachers, and students believe that the female students can do and what the hiring managers on the other side of the educational system believe the females graduates can do. The teachers and parents encourage girls to do and be whatever they want, but when they graduate from STEM university degrees, female graduates get fewer jobs than their male counterparts. This is where the pipeline becomes "leaky" because women graduate from STEM fields of study, and then, leaves when they cannot find the support, employment, or research positions (Blickenstaff, 2005). The pipeline provides female graduates, but hiring managers' and supervisors' misconceptions about their abilities because of their gender have stemmed the flow of women into STEM fields. These biases and misconceptions can include marital bias, or bias against women who may have children, among other things (Blickenstaff, 2005).

However, using examples of successful females in STEM, girls are more likely to enter STEM careers and overcome challenges (Blickenstaff, 2005). For example, women in undergraduate engineering degrees who read biographies of female engineers had more positive attitudes toward mathematics compared to women who read biographies of male engineers (Stout et al., 2011). Furthermore, telling women that STEM fields are becoming more diverse make them more likely to persist when they meet personal and professional challenges (Cheryan, 2012).

A large part of RRI is also ensuring gender balance in science research and education. This is because girls have been proven to be more interested in science education that is based on real-world problems (Sjøberg and Schreiner, 2010). For example, based on the science, mathematics, and technology education (SMT education) research by the relevance of science education project (ROSE project), girls were shown to be more oriented toward "values" when learning science content than boys (2010). Therefore, the ROSE project research demonstrated that girls preferred and excelled in activities focused on topics such as medicine and the environment, which put science concepts they learned into a meaningful context. Indeed, when discussing this finding, Sjøberg and Schreiner note that "one may well argue that the needs of our future society will be better served if potential scientists, engineers, and science teachers see the relevance of SMT to meet the pressing demands of our societies" (2010).

The UNESCO Regional Bureau is committed to achieving the Sustainability 2020 goals set by the UN; one of these goals is to achieve gender equality in work and in education ("Gender Equality and Women's Empowerment," n.d.). Since the Ark of Inquiry Project is an EU-funded science education project with a UN-umbrella organization as a consortium partner, this goal was a key focus during development of the materials used for teacher trainings in the pilot phase in all participating countries.

Teacher Training

Of the key principles noted in the school policy document "Education and Training 2020," very few policies are related to turning teachers from instructors to designers. The document does outline that a focus on ongoing professional development is important and that stakeholders should collaborate to guide the preparation of teacher training courses. This will strengthen the capacity for teachers to move toward learner-oriented teaching and innovation in education (Working Group on Schools Policy, 2015).

IBSE focuses on the idea of the teacher as a "facilitator" in the classroom, rather than the sole "owner" of information (Pedaste et al., 2015). This means that students are encouraged to find their own information and ask questions, and the teacher needs to help them learn the research skills to find the answers. The ability of teachers to teach students the process of scientific research as well as the STEM content is imperative to the students' innovation potential in the future, as students need to be able to solve problems with a robust scientific process. Therefore, the aforementioned ongoing professional development would be a good way to turn teachers from instructors to designers of IBSE learning experiences.

There is also an argument for the need to implement contemporary teaching and learning methods into science subjects; these new methods can help reduce the gap between the STEM knowledge gained in school and its application in the real world (Ault and Dodick, 2010).

According to the American Association for the Advancement of Science, over the past decade, there has been increased interest in inquiry playing a role in science education because it motivates students to learn STEM concepts (Linn et al., 1994). IBSE is becoming increasingly popular. Various projects have come up in Europe which are helping and encouraging teachers in STEM education to adopt and follow methodologies which are more interesting and beneficial to students. This is done through online resource sharing, community formation, conferences, and trainings. Some of these projects include Scientix, The Discover the COSMOS initiative, the Volvox project, and PROFILES project - Professional Reflection-oriented Focus on inquiry-based learning and education through science.

To do this, teachers must acquire the competency to apply IBSE in the classroom. This includes determining the level to which IBSE can be used in understanding a topic, at what level and order the students should acquire the knowledge and skills as well as the choice of STEM content by the teacher and its transformation to suit IBSE.

According to research on the implementation of IBSE in science teacher training, the model of IBSE implementation in science teacher training should consists of the following five stages:

a. Motivation stage: Increasing professional interest and attitudes toward IBSE.
b. Orientation stage: Acquiring knowledge necessary for IBSE.
c. Stabilization stage: Solving of simple applied tasks of IBSE application.
d. Completing stage: Solving of complicated applied tasks of IBSE application.
e. Integration stage: Solving of teaching problem situation in school practice (new skill is integrated into skill structure) (Trna et al., 2012).

The Ark of Inquiry has tried to walk the teachers through these stages using its online resources and the detailed description of activities.

METHODOLOGY

Limitation of Data and Results

While the Ark of Inquiry Project began in 2014 and has a duration of 4 years, the scope of this paper focuses on the implementation phase in Italy, which took place in the Veneto region of Italy. This is due to the fact that our research and analyses took place during internships with the UNESCO Regional Bureau for Science and Culture in Europe (hereafter referred to as UNESCO in-text) in Venice, Italy. The UNESCO is a consortium partner in the Ark of Inquiry Project, responsible for different work packages, including the implementation of the pilot phase in the Veneto region of Italy. However, not all work packages were carried out by the UNESCO, so any other information not directly from this consortium partner has not been included in this report.

Furthermore, our work and analyses focused on teacher feedback from the pilot phase as our internships took place between May and October 2016. The pilot phase survey results from participating teachers were the information available for analysis. This means that some of the recommendations we make in this article are largely pulled from the pilot phase report findings in the Veneto region. Furthermore, the authors of this article helped to prepare the pilot phase report, and some of the suggestions and recommendations may have already been implemented by the UNESCO in subsequent project implementation phases in the late 2016 and early 2017.

This feedback from the Italian teachers in the pilot phase conducted in Veneto, Italy, was qualitative, in the form of annotated responses to interview questions. The coordinators of the project in the Veneto Region of Italy who worked for the project consortium partner, the UNESCO Regional Bureau, conducted these interviews and saved them for analyses on their servers. While this information was requested, it was no longer available and so all of the responses cannot be listed in this article. However, this information was included on the pilot phase report previously mentioned, which was published publicly by the UNESCO Regional Bureau in Venice, Italy, and can be accessed in the references. The authors also cowrote this pilot phase report for the Ark of Inquiry Project in Italy; therefore, the results of this article are focused on this information. Two of the Italian questionnaires, which are the pre- and pos- surveys, can be accessed at https://docs.google.com/forms/d/e/1FAIpQLSfRf_XVzezD6A8K90lDOFg6xcGEuKRbhhNCnms_2vhZoepf2Q/viewform and https://docs.google.com/forms/d/e/1FAIpQLSd22fy7_Nut2feaHTCPxo8l6xfJkkLvajFzr1SiAFFPVAW6IA/viewform, respectively.

One of the limitations of the data collected using the first impressions questionnaire is that most respondents were from India, a developing country where technology is not so widely available in rural and semi-urban areas. The population of respondents we have tapped into for this article come from the people who have access to technology in urban areas. Hence, note that our conclusions do not extend to every population in the whole country. This is true for any survey done in a large country with varied populations and cultures.

Primary Research

Information, statistics, and quotes from participating teachers about the pilot phase are taken from the Ark of Inquiry pilot phase report, completed in July 2016 (UNESCO Regional Bureau for Science and Culture in Europe, 2016). Additional information about the pilot phase, including pre- and post-surveys for teachers, results from the Ark of Inquiry meetings, trainings, and forums, were collected with permission from the UNESCO Bureau for Science and Culture in Venice, Italy.

The pilot phase for the international Ark of Inquiry Project was conducted in 6 months from September 2015 to March 2016. This involved time for preparation and establishment of agreements with schools who wanted to participate in the Ark of Inquiry Project. There were at least 5 schools in each of the 7 countries participating in the pilot phase and 14 participating teachers.

The first type of information collected for analysis included quantitative and qualitative data from surveys conducted before and after the implementation of the Ark of Inquiry pilot phase in Veneto, Italy. We received survey results and statistics concerning the 14 participating teachers from the coordinators of the Ark of Inquiry Project in the Veneto Region. This survey was in Italian and was created and administered by the coordinators before we joined the team. The Italian version is added in the annexure. We assessed the qualitative answers to survey questions asked of teachers online and the written responses from in-person interviews during focus groups and introductory project meetings.

We also received quantitative data from the Google Forms survey “Ark of Inquiry First Impressions Questionnaire,” which included responses from 30 educators from different countries. The survey and the answers have been included in the Appendix B. This questionnaire was created by the authors of this article in our capacity as interns working on this project for research purposes. The responses were anonymous unless the participant wanted to give their name on the Google Form, and the respondents were not required to answer every question in the form. As a result, please note that, the number of responses to certain questions may not be 30. Their answer for each question was voluntary. This survey was disseminated to these educators over our personal social networking sites, including LinkedIn, Facebook, and E-mail. These data does largely represent students studying education at the postsecondary and graduate level and individuals living and working in urban areas in India and Canada. These survey results were exported into.csv files that were analyzed and interpreted for our own research and for internal review by the Science Unit, which can be viewed in the appendix and results section below (Appendix B).

Secondary Research

Some of the results contributing to this article are a consolidation of secondary research done on the topics we thought were primarily important to address the concept of changing the role of a teacher from an instructor to a designer.

FINDINGS

Large barriers to the Ark of Inquiry’s expansion and success as an online IBSE project include the following:

A. The consistent and reliable access to technology by students and teachers to take part in the online project.
   i. Teachers’ capacity to use and manipulate this new technology to make meaningful and relevant scientific learning experiences in the classroom.
   ii. Teachers’ preparedness and prior training to effectively teach IBSE activities.
B. The inclusion of all students, more importantly girls, in science, especially when they face stereotypes about their abilities. These are not limited to Italy but are prevalent in various countries.

30 individuals responded to the “Ark of Inquiry First Impressions” online Google Forms questionnaire. 13 of the 30 respondents self-identified as “Teachers,” and 6 of the 30 self-identified as “Students,” whereas 11 of the 30 self-identified as Education researchers, Vice Principals, and Education Developers. Please note that, “Professor” refers to “University Professor,” and “Student,” in this case, refers to university students studying in the field of Education. Note that, not all of the questions were mandatory to complete, so some of the questions have <30 respondents.

Furthermore, there was one individual surveyed each from Denmark, the USA, Canada, and Germany, and 26 individuals surveyed were from India.

Technology

Many teachers noted that they struggled with the use of technology in the classroom. The scope of technology in this case included the devices that teachers needed to use to connect to the internet and access the Ark of Inquiry platform, as well as the technical skills needed to navigate the online platform. The technical skills were assumed to be basic digital and technological fluency, including being able to open and use a computer, use a word processor, and access the internet effectively. These devices include mobile phones, as well as laptops, desktop computers, and tablets. Each teacher was required to make an Ark of Inquiry platform account and select activities from the platform to implement in their class.

Teachers involved with the pilot phase were enthusiastic about the use of technology. The teachers thought that it was essential that the students were exposed to technology use in the classroom, to prepare them for the future. However, some of the teachers noted that there were issues with the use of technology in the classroom. The following two main issues concerned:

1. Students' varying access to technology. For example, one teacher noted in their feedback that "for most of the activities, only half of the pupils were able to complete the assignment at home."
2. Teachers' understanding of the technology. While the pilot phase requirements for participation included the ability for teachers to use technology, some of the teachers noted that they needed the assistance of a technology teacher. Some teachers also noted that there was no any internet connection at their school, while others noted a lack of computers available for students.

In response to the question "How easy is it to navigate the platform? http://arkportal.ut.ee/#/" on the First Impressions Questionnaire, respondents gave answers on a 1–5 scale, 1 being "Too difficult to Navigate and Use," and 5 being "Very Simple to Navigate and Use." 8 of the 30 respondents rated as a 3, 14 out of 30 of the respondents responded as 4, and 8 out of 30 of the respondents rated 5 (Figure 1).

It is interesting to note that almost all of the respondents answered between 3 and 5 on the question "How easy is it to navigate the platform? http://arkportal.ut.ee/#/?." Following up to this, 22 of the 30 individuals surveyed answered 'Yes' to the question "Would you use these activities in your educational setting (i.e., classroom, outreach events, and organization)?;" however, only 19 of 29 respondents responded "Yes" to "Would you sign up for the platform and become a part of the Ark of Inquiry community?."

It is interesting to note that while all the individuals found the platform easy to navigate, some of the individuals surveyed would use the activities but not join the community. Teachers acknowledged the importance of technology and the role it played in the implementation of most of the activities on the platform. However, they were sceptical about what exactly the students would derive from connecting to the platform online.

Gender

The Ark of Inquiry consortium members created a Pedagogical Scenario document focused on empowering girls in science

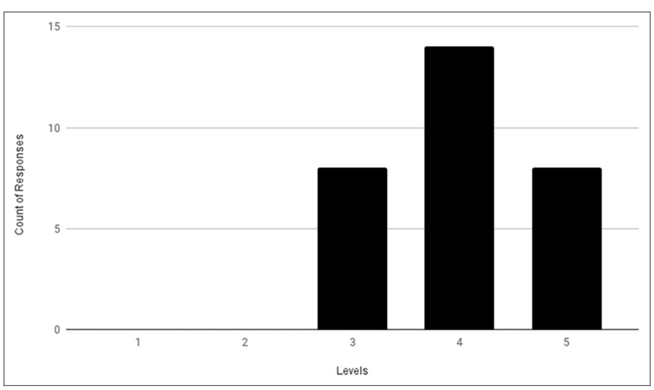

Figure 1: Answers to the question "How easy is it to navigate the platform?" on the Ark of Inquiry First Impressions Questionnaire. Responses from 30 individuals were accounted for in this figure

("Empowering Girls in Science," 2016). This document outlined how teachers could create lessons and content that focused on learning with real-world application. This is because teaching with metacognitive pedagogies that allow individuals to reflect on a problem lets students decide their own procedure to solve a complex problem over time. Studies show that this helps to close the gender gap in performance at least in mathematics (Mevarech and Kramarski, 2014). We would also feel confident extending this finding to other STEM courses of the study.

However, teachers involved in the Pilot Phase of the Ark of Inquiry Project in the Veneto region of Italy reported that they did not fully understand how to use the pedagogical scenario document concerning gender inclusion. They reported that they were not sure if girls were actually being effectively included in their STEM classrooms.

We also received answers from the "First Impressions" questionnaire on the question, "Is the (Ark of Inquiry) project/its activities sensitive to all genders/races/sexes/cultures/backgrounds? If not, what is a suggestion you could give to make it more inclusive?." For example, one participant noted that they would "need more time to go through and understand this (the project) in depth" if they were to answer the question. This means that they were not sure if the project was inclusive, as they had just begun to look at the project for the first time. More time to look at the project before taking the First Impressions Questionnaire may have yielded more robust responses to this question. However, one individual commented that "I believe in (the) inquiry method of learning. In my perspective it is connected with the culture and background…."

Teacher Education

The pilot phase results noted that teachers felt that the support extended by the Ark of Inquiry learning community helped them to understand and implement IBSE. In fact, many of the teachers involved with the pilot phase even volunteered to help fellow teachers understand the IBSE procedures of the project.

In the first impression questionnaire, this issue was touched on with the question, "If you were to receive a "teacher's guide" with lessons and activities printed out in a bound book, would you be able/interested to implement the project? (feel free to expand on your selection in the "Other" section)." The respondents gave varied answers. Of the 30 responses, 17 individuals responded that they would be able to implement the project activities and engage with the project. However, 6 of 30 of those surveyed responded that they would be interested in paper copies of the project materials but were unsure if it would be possible to implement the activities in the same way as with the online component.

DISCUSSION

Technology

In the pilot phase, we saw examples of some teachers struggling with the use of technology. These issues with technology in the span of the pilot phase could have been due to a variety of issues outside of the scope of this project, including the at-home use of personal technology and familiarity with technology in an educational setting. This familiarity and acceptance of technology are important to note as the project continues to expand globally; some schools and cultures are more accepting of technology use in the classroom.

It is common to point to age as a predictor of technological fluency. It is a commonly held belief that digital natives or individuals who grew up with technology are more comfortable with using technology. However, in a study done with pre-service teachers who were digital natives, it was shown that digital natives used technology for their own use at a surface level (e.g., for maintaining a social media presence) rather than for personal learning or deeper understanding of the technology itself (Lei, 2014). This means that comfortable with technology does not predict success with technology in the classroom. To turn teachers into designers of effective IBSE learning activities, they must have the skills to leverage technology for learning purposes.

One of the other notes from the first impressions questionnaire was that some students did not have access to technology at home or even consistently at school. For instance, one teacher stated that "for most of the activities, only half of the pupils were able to complete the assignment at home." If pupils are not able to access the information on the platform on their own, they lose the ability to work on science activities on their own time. This lack of access to technology becomes more of an issue as the project expands internationally. Some communities may have less access to internet connection or technology. Even though 17 of the 30 educators responded that they would be able to implement the project activities and engage with the project if the material was printed out for them, there were 6 of 30 who noted that it may be different than working with the online part of the Ark of Inquiry platform. We also believe that one of the draws of the project is its online community.

We suggest encouraging the use of personal technology such as mobile devices and tablets when school computers or internet are not available. Especially as this project continues to expand globally, its uptake by educators in the classroom may be aided by the "leap-frogging" across the digital divide that has been documented in developing countries (Napoli and Obar, 2013). This term describes the process of skipping traditional desktop computer access to the internet and going straight to the newest mobile technology to access the internet. Leapfrogging has been described as more affordable and accessible than implementing desktop technology solutions. While there are debates about this processes' merits, mostly concerning mobile device memory, and the responsiveness of web pages on mobile devices (Napoli and Obar, 2013), we believe that encouraging the implementation of more personal mobile devices in the classroom to access the internet may aid the Ark of Inquiry Project's uptake across different countries as the project expands.

Influence of language used in the technology platform might also lead to the teachers not being comfortable with the technology. The pilot phase teachers were all teachers with Italian as their first language, and the entire project and portal is primarily in English. This problem of language can also be seen with the respondents of the first impressions questionnaire where a majority of them are from India, and English is not their first language. Similar problems will be faced with teachers all around the world where their first language is not English.

Gender

The confusion over the pedagogical scenario document concerning gender inclusion was in part due to the length of the document and the fact that it was written in English when many of the participating teachers had Italian as their first language. We believe that this kind of problem is quite common when working on large-scale, international education projects; large documents with confusing language can alienate teachers, who already have administrative, classroom, and school community responsibilities to occupy their time and efforts. Lengthy documents may limit teacher's time to actually design engaging IBSE lessons for their classes. Therefore, information and helpful notes about gender inclusion should be succinct and provide concrete examples for teachers to implement in class.

Feedback from the pilot phase of the project also showed that teachers would find it helpful to have more concrete examples of how to include girls more effectively in STEM activities. This feedback was qualitative, in the form of a verbal discussion between teachers involved with the pilot phase of the Ark of Inquiry in Italy and the coordinators of the project in the Veneto Region of Italy who worked for the project consortium partner, UNESCO. While this information was requested, it is no longer available and so exact counts of responses cannot be given. However, this information was included on the pilot phase report previously mentioned, which was publicly published by the UNESCO Regional Bureau in Venice, Italy, and can be accessed in the references.

The teachers involved in the pilot phase in Italy noted that they would appreciate having short, simple documents with strategies, web resources, and examples to help empower girls in day-to-day science lessons.

As a result of this feedback, a simple infographic was created with research and ideas about how to better include girls in the science classroom, mapped onto the 5 phases of inquiry-based learning designed by Pedaste et al., that is the basis of the Ark of Inquiry's phases of the inquiry cycle model (2015) (Appendix A, Figure 3). These infographics have been implemented in many of the countries involved with the project in Europe and continue to be translated into partner languages by participating consortium members. As such, more content such as this could be created by the consortium to help teachers design more inclusive lessons to empower girls in STEM fields.

One suggestion from the Gender Guidelines is to use risk-taking women in STEM fields as role models, to create a representation for girls in the classroom (Appendix A, Figure 3). As mentioned, the incremental theory of intelligence (Dweck, 2007) suggests that intelligence and ability can be acquired through risk-taking. This theory also says that males have been known to be higher risk takers than females, so it is important to motivate female students to take risks and be determined to learn so they will be more likely to learn STEM concepts and innovate in STEM fields. However, this will only be possible when the teachers are clear on how to better include their female students in STEM education; The Ark of Inquiry Project Partner UNESCO produced the Gender Checklist to address this issue (see Appendix A, Figure 3).

One study suggests that during group work in a physics laboratory, it is common for one group member to take control of the experiment, and almost 80% (Holmes and Ido, 2014) of the time, this member is a male student. It can, therefore, be argued that homogeneous groupings of girls in science experiments may be better than mixed-gender groupings, to encourage girls to take more educational risks. Indeed, this is the reason why many science and STEM programs are aimed specifically at girls, to build supportive female relationships in similar STEM fields.

However, this suggestion must be taken with a grain of salt. While it is important to have a supportive group of girls or women in a similar field of study (Shapiro and Sax, 2011), it may also isolate the girls in the STEM classroom and make them less likely to succeed in real-world, mixed-gender STEM work and post-graduate environments. Furthermore, there is evidence showing that girls studying in single-sex schools are not more likely to enter STEM fields than girls who study in coeducational environments (Cherney and Campbell, 2011). Cherney and Campbell's research also showed that girls who completed mathematics test in "stereotype threat" situations (situations where they are confronted with stereotypes about their gender) performed significantly better than girls taking tests in situations that were considered "non-stereotype threat" (2011).

Furthermore, longitudinal research on 37 schools in New Zealand showed that science, mathematics, and english course achievement differences between girls in single-sex and coeducational schools was not significant (Harker, 2000). This shows that exposing girls to stereotypes about their gender and still encouraging them to work in STEM by focusing on their capabilities. It also encourages them to take risks through emulating female role models; the two aforementioned strategies may be successful to apply IBSE in the classroom.

This information also makes the case that all students need to learn to work in groups with high levels of competition if they want to perform in the sciences outside of the school environment. We must recall the pitfalls of the "leaky pipeline," where girls are not aware of the stereotypes that can affect their post-graduate employment prospects. It is also important to note that not all boys are risk-taking, much like all girls are not risk-adverse. If the teacher assigns roles in the group, it may help to solve this problem; one student must collect the data, one must visualize the data, one must write the hypotheses, etc. By meaningfully assigning these roles, girls will be placed in leadership positions where they are trained to take risks and feel confident in their work.

Instead, and as research suggests, basing STEM learning in real-world problems can help include more girls in the classroom (Sjøberg and Schreiner, 2010). These real-world problems include climate change, disease eradication, medicine, and solving food shortages. Designing IBSE lessons focused on these concepts may also make STEM learning more engaging for all students. We suggest focusing most initial IBSE learning experiences in these real-world STEM applications, as many practical questions can come from students, and result in more authentic inquiry experiences based on their own interests. It may also be easier for teachers to design these experiences since real-world, interesting content helps drive student questioning in the classroom.

Barriers to International Implementation of Ark of Inquiry

Since most of the sample of educators for primary research using the "first impressions questionnaire" were from a developing country, we would like to focus this section on barriers to international implementation in a developing country context, using India as an example. These findings correlate with the findings of the research based on Britain by the Education Foundation cited in the literature review section (Technology in Education - A System View, 2014).

The followings are the various challenges to the implementation of the Ark of Inquiry.

- Low internet penetration and use of computers
- Prevalence of traditional classrooms and mind-sets
- Lack of resources, including trained teachers
- Prevalence of different cultures and languages
- Sustainability
- Creation of a community.

Low Internet Penetration and Use of Computers

Although the internet penetration is increasing in developing countries, in India, there is a lack of it in schools with only about 33% of schools having computers with internet (Gupta, 2014). Furthermore, there is no proof of these computers and internet being used in the school for the purpose of learning. For example: "Of the schools I visited, maybe 10% of the computers were working," says Swati Sahni, a consultant who worked for the Indian government on education from 2010 to 2012 (Gupta, 2014).

Prevalence of traditional classrooms and mind-sets

An analysis of teaching-learning at government schools in India will reveal that the teachers prefer to use the traditional method of teaching in classrooms. Some students study outdated material and rote learning is practised to pass examinations. Convincing school administrators and teachers to experiment with inquiry-based learning may be the most tedious task in this country.

One of the mind-sets prevailing in these countries is the value of teachers in the community. The teachers who were traditionally valued and respected have seen a fall in their respect and value which has led to a lesser number of citizens entering the profession. Even the ones who have entered the profession end up holding other kinds of jobs and earning secondary sources of income rather than focusing on their professional development as a teacher. This has been one of the reasons for resistance from the teaching community toward new pedagogical methods and ICT resources, inspite of it being beneficial to the students.

Lack of resources and trained teachers

While the government is focusing on the distribution of tablets and computers to students for studying, they are forgetting that this needs to be added with internet access and teachers who are trained to teach and help the children in using the technology given to them. For implementation of a project such as the Ark of Inquiry, the teachers need to be trained accordingly.

Prevalence of different cultures and languages

As mentioned above, the culture of education prevalent in India is based on the concept of rote learning and achievements based on marks. This culture needs to be addressed to expose the children to the concept of inquiry-based learning, as this method does not focus on rote memorization.

Furthermore, India has a high representation of females in science and engineering programs of the study (around 65% of total enrolment) but very low representation in the science and engineering workforce (about 12.7%) (Huyer and Halfkin, 2013). This shows that though females engage in STEM education, these females either do not work at all or do not work in a STEM-related work environment, likely due to the aforementioned "leaky pipeline" effect (Blickenstaff, 2005).

Countries such as India, Sri Lanka, Bangladesh, and African countries have different languages within their countries. Hence, the project and activities would need to be translated to the appropriate state language. Translating materials into the local language and having interpreters present may require additional resources and/or reduce the amount of content that can be given in a specified time. Not only translating and training the teachers but also the teachers trained would require continuous support in the form of mentors for proper implementation of the Ark of Inquiry Project.

Sustainability

In most developing countries, projects such as the Ark of Inquiry are implemented initially with funding from donor agencies. However, the question arises on how to sustain the project and expand its impact once the initial funding has ended. Enthusiastic teachers might get excited by the idea initially and try to implement it. However, once the funding ends and the resources dry up, they become frustrated and demotivated Wright C.R (2014). This leads them to resist other innovative and advantageous methodologies in their teaching, and they end up following the traditional methods.

Creation of a community

It is clear from the primary research done that while most teachers are interested in the concept of "Ark of Inquiry," there is not proof of them being interested in forming a community. Like most projects, the Ark of Inquiry might struggle not only to interest teachers but also to create a community of them. The main struggle is to get the teachers to work together toward a common goal by creating the community. Along with the unwillingness of teachers to work together as a community, barriers like different languages and online but not real-time presence will amplify this barrier as well.

Teacher Education

We believe that consistent teacher education, with a portion carried out online, would be an excellent recommendation for a project such as the Ark of Inquiry. Teachers would be able to access professional development materials and ideas from around the world through their technology devices. Networks have already been put in place to educate teachers during in-person, local Ark of Inquiry workshops (Teachers from learners to thinkers, 2016). These networks were also established through regular Email correspondence with participating teachers during the pilot phase, but a complete E-learning course on IBSE teaching would be a vital asset to this project. We suggest that consortium partners look into developing these online learning courses, to connect with more teachers internationally and to expand the project.

Online professional development courses called Additional Basic Qualification Courses exist in Canada for Canadian educators. Similar concepts and courses could be put in place for teachers who want to become involved with the Ark of Inquiry Project; professional IBSE qualifications could be given through consortium partners to teachers as incentives for joining and participating on the online platform. Some of these consortium partners are education research universities with focuses in STEM and IBSE. Therefore, they already possess the background knowledge and academic content to develop a robust online course; the researchers at these centers and universities involved in the Ark of Inquiry consortium could use their knowledge to build out the content for these online courses.

This idea of "teacher as designer" became, especially, important when, as mentioned, 22 of the 30 individuals surveyed during the first impressions questionnaire answered "Yes" to the question "Would you use these activities in your educational setting (i.e. classroom, outreach events, organization)?;" however, only 19 of 29 respondents responded "Yes" to "Would you sign up for the platform and become a part of the Ark of Inquiry community?." Please note that, this is one of the situations where only some of the respondents answered the questioned and so there were 29 responses instead of 30. While this disparity may infer that the IBSE activities are popular and valuable to teachers, it also shows that the community may not be as valued by educators. We feel that this needs to change. Teachers should help and learn from each other to understand and implement this new type of IBSE learning and pedagogy.

This is where the role "teachers as designers" is so important. Teachers can design their own classrooms as places of inquiry, but they must also design their own networks of STEM and IBSE education professionals. Designing these networks means that teachers must find like-minded teachers with similar pedagogical interests at the school, community, national, and international level to sustain their passion for this very new and exciting type of teaching pedagogy.

There is no longer room for instructor-led "rote memorization" when it comes to addressing the future innovation potential of Europe. Students must now learn to solve problems based on real-world applications, and IBSE and RRI are a change at the classroom level that cultivates this type of innovative thinking. Therefore, teachers must design and build robust networks of educators who are passionate about this type of technology and learning, thereby supporting themselves as they work to create curious spaces for curious minds. As previously mentioned, they can do this by building robust in-person and online networks of teachers who are passionate about this type of technology and learning. This will support them as they design creative learning spaces. To develop these spaces with correct pedagogical knowledge, they must leverage professional development courses, which we believe would be effectively delivered online by the Ark of Inquiry Project Consortium. The Ark of Inquiry Project could be sustained by these networks, which would make the project sustainable and scalable around the world.

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APPENDICES

Appendix A

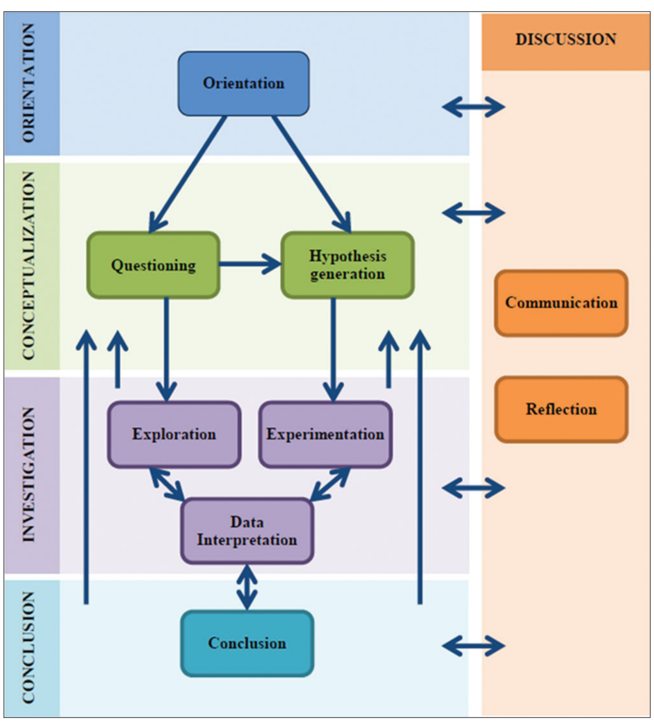

Figure 1: Inquiry model as described by Pedaste et al. (2016). This framework was used to build science, technology, engineering, and mathematics inquiry-based science education activities for the Ark of Inquiry Project

Figure 2: Responsible research and innovation model as described by European Commission that was used for the Ark of Inquiry Project (European Commission, 2012)

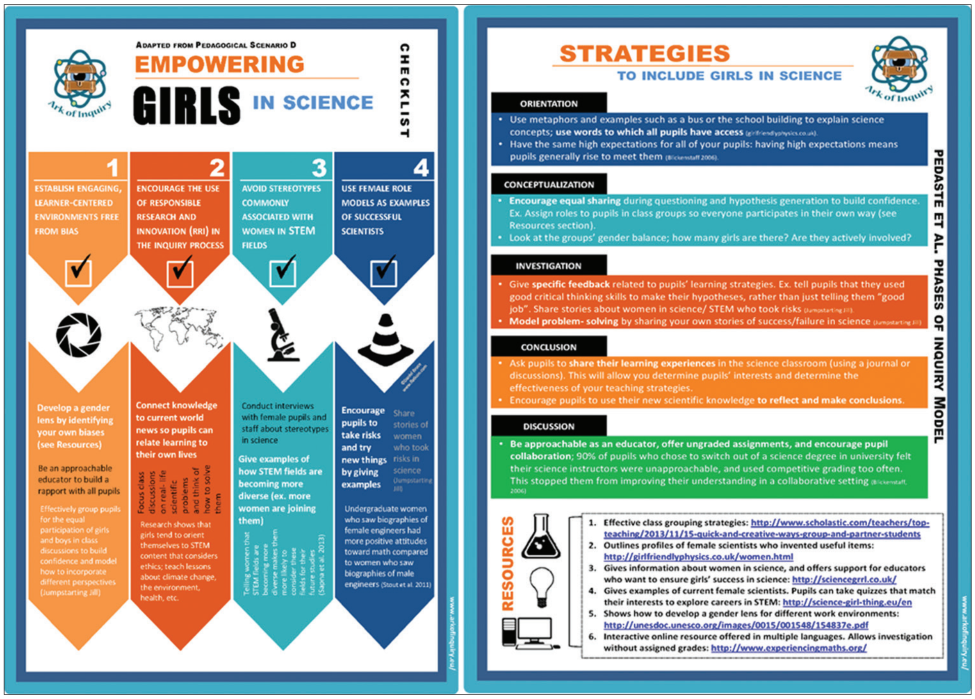

Figure 3: Gender guidelines checklist prepared for teachers involved with the Ark of inquiry, to encourage girls in pursuing science, technology, engineering, and mathematics fields (UNESCO Regional Bureau, Venice, 2016)

Appendix B

Ark of inquiry first impressions questionnaire content

1. What is your profession?
   Student
   Teacher
   Professor
   Researcher
   Other…
2. Where are you from?
   Short-answer text
   Section 2 of 5
3. How would you rate your first impression of the online platform (out of 5)? http://arkportal.ut.ee/#/
   Very poor impression
   1
   2
   3
   4
   5
   Excellent first impression
   Ark of Inquiry Project Logo
4. What do you think of the Ark of Inquiry Logo above? Does the logo convey the message of the project? Why/why not?
   Short-answer text
   Section 3 of 5
5. a) How easy is it to navigate the platform [out of 5]? http://arkportal.ut.ee/#/
   Too difficult to navigate and use
   1
   2
   3
   4
   5
   Very simple to navigate and use
6. b) Did you understand the purpose of each section on the platform (i.e., teacher's toolbox, activities, community, and my inquiry passport?)
   Short-answer text
7. Would you sign up for the platform and become a part of the Ark of inquiry community?
   Yes
   I already did
   No
   Other…
8. Would you use these activities in your educational setting (i.e., classroom, outreach events, and organization)?
   Yes
   No
9. I have used a similar platform or have been a part of a similar project to Ark of Inquiry (please explain in "other" section).
   Other…
   Section 4 of 5

10. If you work in a setting with limited internet access, how do you think the project could be adapted to suit this setting?
    Short-answer text
11. If you were to receive a "teacher's guide" with lessons and activities printed out in a bound book, would you be able/interested to implement the project? (feel free to expand on your selection in the "other" section).
    Yes, I would be able to
    No, I would not be able to
    Interested, but unsure if it is possible.
    Not interested
    Other…
12. Is the project/its activities sensitive to all genders/races/sexes/cultures/backgrounds? If not, what is a suggestion you could give to make it more inclusive?
    Short-answer text
    Section 5 of 5
13. How could the Ark of Inquiry Project be expanded beyond its initial goal to only engage European youth?
    Short-answer text
14. Do you think the Ark of Inquiry Project and its materials would be well-received in your country? Please explain why in the "Other" section.
    Yes
    No
    Other…
15. How could the project be modified to appeal to education practices in your country? i.e. at the school level, the teacher level, the pupil level, administration level?

International Council of Association for Science Education

ORIGINAL ARTICLE

Using Teachers' Inquiry-oriented Curriculum Materials as a Means to Examine their Pedagogical Design Capacity and Pedagogical Content Knowledge for Inquiry-based Learning

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ABSTRACT

The study aimed at examining preservice elementary teachers' inquiry-oriented curriculum materials in an attempt to unravel their pedagogical design capacity (PDC) and pedagogical content knowledge (PCK) for inquiry-based learning (IBL), after attending a professional development program (PDP) centered around inquiry-based teaching and learning. In so doing, we identified the PCK for IBL dimensions (e.g., integration of inquiry within teachers' curriculum designs and evaluation of student learning) underpinning their curriculum materials and for each dimension, we aimed at finding the characteristics of the teachers' curriculum materials and capturing their PCK and PDC concerning that particular dimension. The participants were 44 preservice elementary school teachers enrolled in a PDP that was organized in four phases. In each phase, the teachers were assigned to a different role, namely, teachers as learners (Phase 1), teachers as thinkers (Phase 2), teachers as curriculum designers (Phase 3), and teachers as reflective practitioners (Phase 4). The data sources involved mainly teachers' curriculum materials that were analyzed with the use of grounded theory methodology and the constant comparative method. The data analysis revealed that the teachers' curriculum materials were developed along five PCK for IBL dimensions. Moreover, a number of characteristics of the teachers' curriculum materials were identified for each one of these dimensions, which in turn were clustered along three levels of increased sophistication and revealed our teachers' PDC per dimension. We also managed to identify three different PCK for IBL profiles. Finally, the findings indicate that, even though our preservice teachers attended our specially designed PDP, they have conceptualized in diverse ways the underlying principles of IBL.

KEY WORDS: inquiry; inquiry-based learning; professional development; pedagogical content knowledge; pedagogical design capacity; teacher education

INTRODUCTION

The implementation of inquiry as a learning approach in science classes (i.e., inquiry-based learning; henceforth called IBL) has been a priority for more than three decades (National Research Council [NRC], 1996; 2000; 2007; Van Joolingen and Zacharia, 2009). The goal is to offer to all students the opportunity to enact scientific inquiry, as scientists do when studying the natural world. In this context, students are expected, among others, to state hypotheses, design and conduct experiments, collect and analyze data, reach to conclusions/explanations based on the evidence, and communicate and justify their explanations (Pedaste et al., 2015). Overall, this inquiry framework aims at showing to students that science is driven by research questions which need to be addressed through an open-ended process (Van Joolingen and Zacharia, 2009).

On top of revealing to students how scientists work, IBL is advocated by researchers and educators for its positive influence on students' science learning. It was found to have a positive impact both at an affective and a cognitive domain level (e.g., Lazonder and Harmsen, 2016; Minner et al., 2010). Therefore, many science curriculum reforms across the world have highlighted inquiry as one of the teaching approaches to be used within science classes (Kearney, 2011; Rocard et al., 2007).

Despite the multiple learning benefits that learners experience when engaged in inquiry-based activities, IBL continues to be absent from teachers' ordinary teaching practice repertoire (Kearney, 2011; Rocard et al., 2007). This failure might be attributed to several factors such as teachers' lack of knowledge about IBL, teachers' lack of skills for enacting IBL within a science class, teachers' personal choices of more direct and teacher-centered teaching approaches, or to the lack of proper resources, and lack of activities in school science textbooks that could be implemented through IBL (Crawford, 2016).

Research has shown that the teacher is the crucial player in implementing IBL (e.g., Keys and Bryan, 2001; Wallace and Kang, 2004). In so doing, they need to have, among others, a deep understanding of scientific inquiry, strong practical experience with designing, developing, implementing and assessing IBL, and skills for guiding and organizing students to conduct inquiry activities (Jeanpierre et al., 2005; Van

Joolingen and Zacharia, 2009). Magnusson and Palincsar (1995) argued that IBL also depends on the teacher's pedagogical content knowledge (PCK). PCK comprises a teacher's content knowledge, pedagogical knowledge, and knowledge about the context where a teacher works (Gess-Newsome, 1999). In the case of IBL, it was found that for its effective implementation teachers must possess high-level PCK for IBL (Crawford, 2000).

While research has revealed a number of factors explaining the failures and successes of IBL implementations in science classes, we are still missing a framework which guarantees effective professional development programs (henceforth called PDP) for teachers on learning about inquiry and later on adopting it in their own science classes (for a thorough review see Irakleous, 2015). Consequently, current research places emphasis on how best to prepare teachers to design and enact science instruction through IBL. It has been emphasized that PDPs need to involve teachers (among other activities) in designing their own curriculum materials (Voogt et al., 2011), because this type of challenge (i) provides opportunities for teachers to reflect on the curriculum starting from their personal knowledge, beliefs, and their goals for student learning (Parke and Coble, 1997), (ii) helps teachers to develop ownership and commitment for effective implementation of their curriculum (Bhusal, 2015), and (iii) contributes in (re) shaping their own practice (Voogt et al., 2011).

Preparing preservice teachers for implementing IBL is even more challenging because they have limited experience in the classroom and, as a result, they fail to translate IBL theory and frameworks into classroom practice (Haefner and Zembal-Saul, 2004). In addition, they have limited experience in designing and implementing IBL curriculum materials. According to Avraamidou and Zembal-Saul (2010), the preparation of preservice teachers must offer opportunities to experience curriculum materials (e.g., through the phases of design and implementation) that they will use later on as in-service teachers. Hence, it is important for preservice teachers to experience IBL not only at a theoretical level but also at an empirical/practical level (i.e., through the design and implementation processes), before entering schools as in-service teachers.

In this study, we aim at contributing toward this line of research. Specifically, we offered the opportunity to preservice teachers to design and develop IBL curriculum materials after attending a specially designed PDP. In this PDP we required from teachers to undertake a series of roles (i.e., learner, thinker, designer, and reflective practitioner) to offer them the opportunity to see inquiry and IBL from different angles/perspectives and, thus, develop a more coherent understanding of inquiry and IBL. The overall idea was to examine how an inquiry-oriented PDP, which has been developed and refined after a thorough literature review of the domain (for details see Irakleous, 2015), influences the development of preservice teachers' IBL understandings both at a theoretical (e.g., what IBL is and how it is enacted) and practical (e.g., designing IBL curriculum materials) level. For accessing these understandings, we collected and analyzed their IBL curriculum materials, which they were the end products (i.e., artifacts) to be produced by the preservice teachers in our PDP. This research falls under the wider efforts of optimizing PDPs for introducing IBL to preservice teachers.

THEORETICAL BACKGROUND

Teachers are the key players of implementing IBL (Crawford, 2000). However, implementing IBL has proven to be a hard task, especially for newer teachers (e.g., Papaevripidou et al., 2017). As a result, researchers have been urging the science education community, to develop proper PDPs for training teachers to understand what IBL is about and how it could be implemented in their own science classes. Over the years, it became apparent that training teachers to use ready-made inquiry-based curriculum materials (i.e., instructional resources, such as lesson plans, activity sheets, and textbooks) were not enough for preparing teachers to implement effectively IBL curriculum materials in their classes and, to do so, the teachers themselves had to get involved with the design process of these curriculum materials, as well (e.g., Ball and Cohen, 1996; Brown et al., 2006; Kim et al., 2007). In other words, research has highlighted the importance of having teachers, especially preservice ones, experience the curriculum materials to be used in their future teaching (Remillard, 2005), as well as the importance of designing such materials on their own (Brown et al., 2006; Kim et al., 2007; Papaevripidou et al., 2017).

However, revising existing curriculum materials or designing and developing new ones requires from the teacher to use a significant amount and variety of resources (Knight-Bardsley and McNeill, 2016). The identification and use of these resources depend on the teacher's pedagogical design capacity (PDC; Brown, 2009). PDC is defined as the teacher's competence to identify the necessary resources, either through his/her own personal resources (i.e., subject matter knowledge, beliefs, and PCK) or the resources embedded in the curriculum materials (i.e., physical objects, domain representations, and procedures) themselves, to design and develop curriculum materials or alter existing ones (Brown, 2009; Knight-Bardsley and McNeill, 2016). According to Brown (2009), who initially introduced the construct of PDC, teaching could be considered as a design activity, in which teachers use resources, personal and curriculum related ones, to enact teaching that promotes student learning. Brown has situated the whole PDC process while teaching in a class, during which teachers design at a real-time their own instructional episodes by altering the existing curriculum materials or by improvising and developing new ones. In this study, we use a broader definition of PDC, as argued by Knight-Bardsley and McNeill (2016), which includes all available instructional resources (e.g., PDPs and instructional tools) and not just curriculum resources. Given this, we examine preservice teachers' PDC through their developed IBL oriented curriculum materials. In this context, preservice teachers are expected to make pedagogical decisions and use personal and instructional resources, including the ones introduced through our specially designed PDP, to accomplish particular IBL related instructional goals, which in turn are transformed into IBL curriculum materials. In this respect, teacher's IBL curriculum materials could be used as the means for examining a teacher's PDC. For instance, the IBL curriculum materials (e.g., lesson plans, instructional tools, and activity sheets) could reveal the personal and instructional resources used by the teacher during the design and development process of the materials.

Teachers' capacities for designing IBL curriculum materials could evolve through training (Feiman-Nemser, 2001; Irakleous, 2015; Papaevripidou et al., 2017). In this respect, preservice teachers need to be engaged in training through PDPs to develop and improve their PDC for IBL. Such training is crucial since novice teachers carry a number of insufficiencies such as insufficient understanding of what inquiry is, how IBL activities are designed, and what resources are necessary to design and develop proper IBL curriculum materials (Abell, 2007; Davis et al., 2006; Forbes and Davis, 2010). Supporting the development of preservice teachers' PDC for IBL during their teacher education years could offer them the opportunity to start their science teaching career as well prepared as possible. However, to succeed in this endeavor, we first "need to better understand how teachers draw on their instructional and personal resources" (Knight-Bardsley and McNeill, 2016, p. 648). Without such an understanding, it would be impossible to design proper PDPs that target the enhancement of preservice teachers' PDC for IBL.

One of the major personal resources that teachers' draw on is PCK (Brown, 2009; Knight-Bardsley and McNeill, 2016). PCK is a multifaceted construct, which entails among others knowledge of the learners (e.g., knowledge of their needs, difficulties, skills, and competencies), knowledge of the curriculum and teaching materials, knowledge of the learning approach to be implemented (e.g., inquiry) and its associated learning strategies, knowledge of how to assess learners, and knowledge of why all these (e.g., curriculum, learner needs and competencies, teaching method and strategies, and assessment) are needed for promoting student learning. Magnusson et al. (1999) have reported five PCK dimensions needed for science teaching, namely, knowledge of orientations toward science teaching, curriculum and teaching materials, learners' background and capabilities/competencies, instructional strategies, and assessment. Davis and Krajcik (2005) have further extended the aforementioned dimensions to encompass inquiry (i.e., PCK for IBL). Specifically, the construct of PCK for IBL requires knowledge of orientations congruous with the inquiry, students' perception of inquiry, inquiry-based teaching materials, learning strategies for implementing inquiry, and techniques for assessing inquiry. Even though, in this study, we identify our own dimensions of PCK for IBL through grounded theory methodology (Section 3.3), there is a considerable overlap between the dimensions of Davis and Krajcik (2005) and ours. We have not used the dimensions of Davis and Krajcik (2005) because of the nature of our PDP (i.e., teachers experiencing inquiry through different roles). We also wanted to see the dimensions coming out from our data analysis than fitting our data in existing dimensions, which were the result of studies with a different context.

Brown (2009) argued that teachers use PCK as a resource to design instruction, which means that looking into teachers' own IBL curriculum materials should reveal their PCK for IBL, which in turn reflects on their PDC (e.g., poorer PCK results in poorer personal resources, which in turn result in lower PDC). Hence, in this study, we examined both preservice teachers' PCK and PDC for IBL through their own IBL curriculum materials. By having such an insight, it could prove useful for identifying the support needed to enhance teachers' PCK and PDC in a PDP.

One of the critical aspects of this study was the study's PDP itself, which was designed after a thorough review of the literature of the domain (Irakleous, 2015). The primary goal of this PDP was to introduce IBL to preservice teachers. To do so, the preservice teachers had to undertake a number of roles to experience IBL through different perspectives. According to this framework, teachers have to enact four distinct roles, namely, teachers as learners, teachers as thinkers, teachers as curriculum designers, and teachers as reflective practitioners.

Having teachers undertake the role of active learners was found to benefit teachers' professional development because it allows them to experience the same learning paths as their students (Clarke and Hollingsworth, 2002; Kazempour and Amirshokoohi, 2014), which eventually result in enabling teachers' understand what inquiry is about and what skills it requires (Loucks-Horsley et al., 1998).

The role of teachers as thinkers involves reflecting on the learning experiences gained when undertaking the role of the learner in combination with the theoretical underpinnings of inquiry, which come from the PDP facilitators. Theoretical readings, class discussions, and other reflective activities could be used to support teachers to develop a theoretical framework about IBL (Akerson et al., 2007).

The role of the teacher as a designer requires moving from theory to practice. In this case, teachers are asked to transform their understandings of inquiry into IBL curriculum materials. This means that by looking into their IBL curriculum materials, someone could infer their perspectives on inquiry and IBL.

Finally, the role of the teacher as a reflective practitioner requires from teachers to implement their IBL curriculum materials into their own classes, adjust their teaching according to their participants needs, collect evidence to evaluate and reflect on the effectiveness of their teaching, and bring reports of their field experiences to the course and analyze teaching strategies with their mentors and colleagues. Ferraro (2000) has strongly argued about positioning teachers in such a reflection mode since it positively affects teachers' professional development.

For the purposes of this study, we focused on the IBL curriculum materials that our preservice teachers designed, developed and implemented when attending our PDP. More specifically, we examined their IBL curriculum materials, which were designed and developed within the teacher as a designer phase and were later implemented during the teacher as a reflective practitioner phase. First, we identified the PCK for IBL dimensions underpinning their curriculum materials and, second, for each dimension we aimed at finding the characteristics of their curriculum materials to capture their PCK and PDC.

In particular, we aimed at addressing the following questions:

1. What are the characteristics of preservice teachers' IBL curriculum materials after the study's PDP and what information do they provide concerning their PDC for IBL?
2. What information do the characteristics of preservice teachers' IBL curriculum materials provide concerning their PCK for IBL?

METHODOLOGY

Participants and Setting

The participants were 44 preservice elementary school teachers (n females=32, n males=12) who were attending an undergraduate elementary teaching methods course in the context, of which the PDP was enacted. The PDP, which was taught by two university professors and three teaching assistants, was split into four phases according to the four distinct roles that teachers were assigned to during their participation in the PDP. These were as follows: Teachers as learners (Phase 1), teachers as thinkers (Phase 2), teachers as curriculum designers (Phase 3), and teachers as reflective practitioners (Phase 4).

Procedures

During Phase 1 (teachers as learners), the teachers worked in pairs and went through three IBL curriculum materials, namely, inquiry learning spaces (ILSs), in the context of electric circuits and one in the context of the extinction of dinosaurs. An ILS is an online computer-supported environment that fosters IBL designed in the context of the Go-Lab project (http://www.go-lab-project.eu/). The developer of an ILS can integrate remote or virtual labs (http://www.golabz.eu/labs) and a number of apps/tools (http://www.golabz.eu/apps) to support learners' IBL as they move through the different inquiry phases suggested by the Pedaste et al. (2015) inquiry learning framework. The four ILSs were completed by the participants in four 1.5 h meetings.

In the first meeting, the participants engaged with the first ILS that consisted of five inquiry phases, namely, the orientation, the conceptualization, the investigation, the conclusion, and the discussion phase. The teachers were introduced to electric circuits, starting from the simple electric circuit and transitioned to series and parallel circuits. In the orientation phase, they watched a video to collect useful information about the different ways of connecting electrical circuits. In the next phase, teachers formulated investigative questions and hypotheses about the relationship between the number of light bulbs and their brightness (e.g., how the brightness of light bulbs is affected by the addition of light bulbs in a series and in a parallel circuit). The formulation of their investigative questions and hypotheses was accomplished through two apps, namely, the question scratchpad (i.e., tool for forming research questions) and the Hypothesis Scratchpad (i.e., tool for forming hypotheses). These apps entailed predefined concepts and conditions that the teachers could drag and drop to generate investigative questions and hypotheses. In the investigation phase, they designed their experiments with the use of the experimental design tool (i.e., tool for designing an experiment). Specifically, the teachers used this tool to select from the given set of variables the variable that should be altered (independent variable), the variable that should be measured (depended variable) and the variables that should be kept constant. In doing so, the teachers should define and then drag the appropriate variables in the "vary," "measure," and "keep constant" columns. Then, the teachers used the electric circuit lab to perform their valid experiments and to collect data. Specifically, the teachers set the number of bulbs in a series circuit and afterward in a parallel circuit. When they run the experiment, they recorded their observations about the brightness of the bulbs when the number of bulbs increased or decreased with the use of the experimental design tool. Once they felt that they collected enough data that could be used to answer their investigative question and the related hypothesis, they moved to the conclusion phase. In this phase, teachers used the conclusion tool (i.e., tool for writing evidence-based conclusions) to check whether the data collected could be used to support the hypotheses developed previously in the hypothesis scratchpad tool and answer the investigative questions posed in the question scratchpad tool. Specifically, the conclusion tool offered the possibility to teachers to retrieve their hypotheses and questions to argue if their hypotheses could be confirmed or rejected.

In the subsequent two meetings, the teachers engaged with two additional ILSs in the context of electric circuits that maintained the same format with the previous one. Specifically, in the context of the second ILS, the teachers have investigated the relation between the number of light bulbs and the total electric current, first in a series circuit and then in a parallel circuit. In the context of the third ILS, the teachers were introduced in the concept of resistance and then to Ohm's law, as the purpose of this ILS concerned the investigation of the relation between the voltage and current in a series and parallel circuit.

The difference between each ILS lied on the type of supports and scaffolds that teachers could receive throughout the curriculum. The inquiry activities that were included in the first ILS were guided mostly by the instructors and the activity sequence that both provided structured scaffolding to teachers to foster their familiarization with the inquiry. In the context of the subsequent ILSs, the teachers shifted from structured inquiry to guided inquiry (ILS 2) and finally to open inquiry (ILS 3). The degree of learner autonomy was increased throughout the activity sequence, and consequently, the level of instructor intervention and guidance fainted out.

After the completion of these ILSs, the teachers as learners engaged with another ILS in the context of the "Dinosaurs extinction." Specifically, the teachers initially were prompted to reflect on why the dinosaurs extinct in the past, and then examined the implications of the assumption that dinosaurs' extinction was caused by an asteroid that fell on Earth. The purpose behind engaging teachers with this specific ILS was two-fold. First, we aimed at giving teachers as learners the opportunity to engage in a new subject domain to see the impact of inquiry on facilitating learners' understanding and development of inquiry competence in a new context. Second, given the fact that the context of dinosaurs' extinction concerns a compelling topic for learners across ages to deal with, this ILS would be given to teachers to use it as the starting point to familiarize their students with the inquiry process and the tools used in an ILS for the purposes of the science fair project (Phase 4, teachers as reflective practitioners for more details).

During Phase 2 (teachers as thinkers), the teachers were asked to study the ILSs they previously worked with to identify the phases of inquiry and their interconnections, to inductively formulate the underpinnings (i.e., PCK for IBL) of the inquiry-based framework that guided the design of the environments. After that, the instructors of the course provided to the teachers a theoretical paper that focused on the inquiry learning and the inquiry learning cycle suggested by Pedaste et al. (2015). They were asked to compare it with their perceived frameworks and to reflect on how the reading of paper enhanced their knowledge about inquiry learning and teaching. The goal was to reflect on their perceived PCK for IBL.

During Phase 3 (teachers as curriculum designers), the teachers were asked to form pairs, choose a topic among a given list of subject domains (Table 1) from the national curriculum of the upper elementary school classes, and design their own ILS that would implement it with an elementary school student for the purposes of a Science Fair project. In so doing, the teachers were expected to study the existing curriculum materials that appear in the school textbooks and make an effort to redesign them (i.e., PDC for IBL) to transform them into a sequence of inquiry learning activities progression. It is important to note that even though the existing national curriculum materials are in the process of reform, through which all curriculum materials will be developed on the tenets of IBL, a big part of the curriculum materials are still inconsistent with the IBL framework (i.e., the framework of Pedaste et al., 2015). The selected topics that were given to teachers to choose from correspond to curriculum materials that were not aligned with the IBL framework (i.e., not aligned with the framework of Pedaste et al., 2015) that the participants became familiar as learners and as thinkers during Phases 1 and 2, respectively. Consequently, the purposeful selection of these curriculum materials was expected to serve as a design challenge for the participants to illustrate how their PCK and PDC for the inquiry would inform their curriculum designs.

Table 1: Teachers' topic selection used for the design of their ILS

Pair	Unit's topic
1, 6	Friction
2	Free fall
3	Balancing
4, 5	Light: Shadows
7	Hydrostatic pressure
8, 10	Sinking and floating
9	Static electricity
11	Color light
12, 13	Light: Lenses
14	Simple pendulum
15	Light diffraction
16	Springs
17, 21	Acids and Bases (Ph)
18, 20	Transfer of heat - thermal insulation materials
19	Forces
22	Electromagnetism

ILS: Inquiry learning space

To facilitate teachers as curriculum designers' role, a set of tasks organized into stages were followed. Specifically, at first stage, the instructors of the course administered a Science Fair Proposal Assignment to teachers to help them organize the inquiry activities that would incorporate in the ILS. The teachers were prompted to design activities that would be aligned with the principles of IBL and the phases of inquiry they went through as learners proposed by Pedaste et al. (2015). The proposal consisted of three parts. In the first part, they had to state the problem that would be integrated into the orientation phase and mention the related variables. In the second part, they were asked to formulate two investigative questions and the corresponding hypotheses that would be tested in the context of two inquiry cycles. In the third part, they were prompted to provide all necessary information and documentation on important aspects of their investigations such as (i) Which variables would be altered and how? (ii) Which variables would be measured and how? (iii) Which variables would be kept constant and how? and (iv) What equipment would be needed for conducting the experiments? The proposal was used as a plan that would assist teachers in thinking the organization and content of the orientation, conceptualization and the investigation phases of their ILS. Teachers received feedback by the course instructors on their completed proposals before proceeding in transforming their inquiry proposals in activity sequence in the form of ILS.

As a second stage, they were asked to develop their ILS with the use of the authoring tool of the Go-Lab platform, which allows teachers to integrate tools and resources that are uploaded on the Go-Lab platform, in phases consistent with the Pedaste et al. (2015) IBL framework (see more info at www.golabz.eu). To engage their students in authentic investigations, the teachers were asked to use physical and virtual labs for conducting the experiments for the purposes of the first and second inquiry cycles, respectively. Furthermore, the teachers were asked to design assessment tasks to capture and monitor their students' inquiry skills (i.e., identifying variables, interpreting data from a table, identifying flaws in an experimental design, etc.) and content knowledge that related to the subject domain of their project.

During Phase 4 (teachers as reflective practitioners), the teachers in pairs collaborated with an elementary school student (age of students ranged between 10 and 12) with whom they met during afternoon hours at their home to engage him/her in IBL through two ILSs. The first ILS concerned the "dinosaurs' extinction" (it was the one that teachers themselves went through during Phase 1 of their training), whereas the second ILS was the one they designed during Phase 3. The emphasis of the implementation of the first ILS was to help students familiarize themselves with the inquiry process, i.e., formulation of investigative questions and hypotheses, conduction of an investigation that enabled the identification and testing of variables that affect the size of a crater caused by the fall of an asteroid, drawing of conclusions, etc. The implementation of the first ILS was accomplished in two meetings of 60 min each. During the subsequent meetings with their student (the frequency of meetings varied from 6 to 10 meetings), the teachers implemented the ILS they developed as part of their training in the third phase of the PDP. Throughout the meetings, the teachers were asked to keep reflective journals in which they described the procedure followed in guiding their student through each phase and stage of inquiry-based cycle. Furthermore, they were asked to present the assessment tasks they designed for capturing their student's development of inquiry competence and conceptual understanding, the actual responses provided by their student and elaborate on his/her learning difficulties.

By the end of the course, the teachers guided their student in preparing a poster to report on all phases of inquiry they went through during the implementation of the second ILS. This poster, along with practical investigations related to their subject domain, was presented during the Science Fair day at their school. During the Science Fair, the participants shared their reflections and received feedback from the instructors and peers.

Data Collection and Methods of Analysis

To answer both research questions, multiple data sources were collected, namely: (i) The science fair proposal assignments, (ii) the ILSs that teachers developed, (iii) teachers' reflective journals that were maintained during implementing their ILSs with their student, and (iv) assessment tasks developed by the teachers and students' responses on these tasks that pertained to their initial and final status about inquiry competence and conceptual understanding about the subject domain of their ILS.

Grounded theory methods (Charmaz, 2006), in conjunction with the constant comparative method (Glaser, 1965) were followed for analyzing the collected data. Specifically, the main focus during the analysis was on the content and the structure of the activities that teachers incorporated within their ILSs, while at the same time attempts were made to identify possible links between these activities and their Science Fair proposal assignments, and links between the inquiry learning framework that the teachers were already familiar with during Phase 2, and their teaching and learning experiences reported in their reflective journals. After several iterations of data examination, the focus of the analysis became broader, and finally, five PCK for IBL dimensions were elicited that were considered as critical to guide the identification of the characteristics of teachers' curriculum materials illuminated in their ILSs. The five dimensions that were revealed from the data analysis were as follows: (i) Teachers' curriculum design orientation, (ii) degree and type of reconstruction of the national curriculum unit, (iii) types of the designed activities, (iv) integration of the inquiry learning cycle within their curriculum designs, and (v) evaluation of students' learning gains. Given that these dimensions concern teachers' pedagogical decisions and provide evidence about the personal and instructional resources they used during the design, development, and implementation process of their curriculum materials, the revealed dimensions were considered as a multifaceted prism through which inferences about their PDC and PCK for IBL statuses could be extracted.

To draw inferences about teachers' PDC for IBL (Research Question 1), we looked at the characteristics that were elicited for each dimension of analysis. In doing so, the following steps were followed:

1. The derived characteristics for each dimension of analysis were grouped in clusters that shared commonalities and were subsequently coded in terms of the main themes they represented. Although codes were developed *in vivo*, using the participants' own language within their reflective journals, other codes were developed with insights from previous literature. For instance, Miller and Seller's (1990) curriculum design orientations were used as a coding scheme for characterizing teachers' curriculum design orientations. Miller and Seller suggested three broad orientations (i.e., (i) transmissive, (ii) transactive, and (iii) transformative) that pertain both on the teacher's and student's role during the learning process and reflect how teaching and learning are facilitated in the context of a classroom environment. More specifically, a transmissive curriculum design orientation assumes knowledge is content, controlled by the teacher, and transferred to students through demonstration and telling. A transactive curriculum design orientation, on the other hand, assumes knowledge is constructed by learners through the process of learning, and the role of the teacher is to facilitate learning and to create environments which stimulate

learners' interests, recognizing that learning is social and at the same time individual. Finally, a transformative curriculum design orientation refers to the case of curricula that learning is developed through self-reflection, self-awareness, and self-learning; the learner is offered opportunities to "reassess new knowledge in relation to existing knowledge and reflect on the underlying assumptions and biases that are the foundation of that existing knowledge" (Harris and Cullen, 2009, p. 57).

2. The emerged clusters were compared and contrasted in search of commonalities and differences in an attempt to reduce the number of clusters and integrate them into broaden categories.
3. During steps 1 and 2 we used teachers' reflective journals for triangulating the emerged clusters. Evidence from their reflective journals helped in understanding the rationale, struggles, emotions, and decisions followed by the participants during designing and enacting their curriculum materials. For instance, there were cases of teachers who expressed concerns about how to proceed when their students encountered specific difficulties during their enactments and expressed emotions like "I don't feel confident enough to deal with this…" or "I felt insecure when my student asked me about this…," etc.
4. Three distinct categories of characteristics for every dimension of analysis resulted after the second round of review, and after labeling them according to the characteristics they encompassed, they were hierarchically ordered in terms of the sophistication of the resulting outcomes. The most inferior category was labeled as Level 1, the most superior category as Level 3, and the one between as Level 2. We consider Level 1 to be the lower level of teachers' PDC, whereas Level 3 to represent the highest level of teachers' PDC.
5. Finally, the frequency of the 22 pairs of teachers' distribution along the five dimensions of analysis of their curriculum materials and across the emerged levels was calculated.

To draw inferences about teachers' PCK for IBL (Research Question 2), we combined information from Table 2 (PCK for IBL dimensions of teachers' curriculum materials, characteristics of each dimension, and emerged sophisticated levels) to Table 3 (classification of pairs of teachers' curriculum designs in the emerged levels along the five PCK for IBL dimensions). Given that our PCK and IBL dimensions resemble aspects of teachers' PCK for IBL suggested by other frameworks reported in the literature (Magnusson et al., 1999; Davis and Krajcik, 2005), in conjunction with the fact that homogeneity was found in the classification level for the majority of pairs of teachers' curriculum designs across the five dimensions of analysis (17 out of 22 pairs were classified in the same level for each dimension of analysis), we postulated that there exists a pattern to account for how the participants of the study designed and implemented their curriculum materials. As a result, we looked into the characteristics within each of the emerged levels for all the dimensions of teachers' PCK for IBL as a whole and extracted information about their PCK for IBL. Consequently, the characteristics that fell under each level enabled the identification of three different teacher profiles in terms of their PCK for IBL.

Finally, inter-rater reliability was followed and calculated during all steps of the coding process. In particular, 50% of the data was assessed by two independent coders, and the ratio of the agreement was calculated. The coders agreed on 89% of the coding in step 1, 87% in step 2, and 93% in step 3 of the process of analysis followed for answering research question 1, and on 94% in clustering individual teachers into the emerged profiles (research question 2). The differences of the coders in each coding step were solved after discussing them with the authors of the paper, and necessary adjustments and revisions were performed. Next, the other 50% of the data was used by the same independent coders for the second round of inter-rater reliability examination, and the agreement was 100%.

FINDINGS

The findings are presented in two subjections; one per the study's two research questions that this study aimed to address.

What are the Characteristics of Preservice Teachers' IBL Curriculum Materials after the Study's PDP and What Information do they Provide Concerning their PDC for IBL?

The characteristics of preservice teachers' IBL curriculum materials are presented below for each of the PCK for IBL dimensions, as they resulted from our analysis, separately. For each dimension, we also provide teachers' PDC for IBL with an increased sophistication (i.e., Level 1 through Level 3; Table 2).

Teachers' curriculum design orientation

The analysis of teachers' curriculum designs revealed three PDC levels with increased sophistication in terms of their curriculum design orientation that are described below.

Level 1 - Transmissive curriculum design orientation

This PDC level concerns the case of curriculum materials where the learner has a passive role, since the teacher focuses on rote learning, lecturing, and conceptualizes the learning experience as a transmission of facts, concepts, rules, and norms. The analysis revealed that six of the curriculum designs were clustered in this level.

A representative example of the activity sequence of a curriculum design in the context of "Sinking and Floating" that was clustered in Level 1 is provided in Table 4 and elaborated afterward.

According to Table 4, the teachers of pair 10 begin their instruction by providing their student with a scenario that relates to the materials that should be used for constructing a ship to be able to float in water. Although the student is expected to propose materials that might help the ship is floating in water, the activity that follows does not take into account the student's ideas. Instead, the teacher asks their

Table 2: PCK for IBL dimensions of teachers' curriculum materials, characteristics of each dimension, and emerged PDC levels of sophistication

	Level 1	Level 2	Level 3
(i). Teachers' curriculum design orientation	Transmissive curriculum design orientation	Transmissive and transactive curriculum design orientation	Transactive and transformative curriculum design orientation
(ii). Degree and type of reconstruction of the national curriculum unit	Replication of the national curriculum unit modification only of the problem provided to students	Partial reconstruction of the national curriculum unit design of extra inquiry activities	Total reconstruction of the national curriculum unit with strong priority to IBL
(iii). Types of the designed activities	Very structured inquiry activities - Conceptual understanding development is either missing or accomplished through delivery of ready-made statements - partial scaffolding	Structured and guided inquiry activities - introduction of concepts through examples from everyday life – conceptual and procedural scaffolding	Guided and open inquiry activities - Conceptually oriented activities interconnected with the inquiry activities - conceptual and procedural scaffolding that faints out gradually
(iv). Integration of the inquiry learning cycle within their curriculum designs	Inquiry as a linear process	Inquiry as a linear process but sometimes students are prompted to go back to recall what has been done or learnt	Inquiry as a cyclical and iterative process
(v). Evaluation of students' learning gains	Pre- or post-evaluation of students' rote learning through closed-ended questions	Pre- and post-evaluation of students' understandings about concepts relevant to the topic engaged with open-ended tasks	Pre- ongoing and post-evaluation of students' inquiry skills and understandings about concepts relevant to the topic engaged with open-ended tasks

PCK: Pedagogical content knowledge, IBL: Inquiry-based learning, PDC: Pedagogical design capacity

Table 3: Classification of pairs of teachers' curriculum designs in the emerged levels along the five PCK for IBL dimensions

Dimensions of analysis of teachers' curriculum materials					
	(i). Teachers' curriculum design orientation	(ii). Degree and type of reconstruction of the national curriculum unit	(iii). Types of the designed activities	(iv). Integration of the inquiry learning cycle within their curriculum designs	(v). Evaluation of students' learning gains
Pair 1	L2	L2	L2	L2	**L1**
Pair 2	L1	L1	L1	L1	L1
Pair 3	L2	L2	L2	L2	L2
Pair 4	L2	L2	L2	L2	L2
Pair 5	L1	L1	L1	L1	L1
Pair 6	L1	L1	L1	L1	L1
Pair 7	L2	L2	**L1**	L2	L2
Pair 8	L3	L3	L3	L3	L3
Pair 9	L2	L2	L2	L2	L2
Pair 10	L1	L1	L1	L1	L1
Pair 11	L3	L3	L3	L3	L3
Pair 12	**L2**	L3	**L2**	L3	L3
Pair 13	L3	L3	L3	L3	L3
Pair 14	L3	L3	L3	L3	L3
Pair 15	L3	L3	L3	L3	L3
Pair 16	L2	L2	L2	L2	L2
Pair 17	L3	L3	L3	**L2**	L3
Pair 18	L2	**L3**	L2	L2	L2
Pair 19	L3	L3	L3	L3	L3
Pair 20	L1	L1	L1	L1	L1
Pair 21	L3	L3	L3	L3	L3
Pair 22	L1	L1	L1	L1	L1
Frequency	*L1=6, L2=8, L3=8*	*L1=6, L2=6, L3=10*	*L1=7, L2=7, L3=8*	*L1=6, L2=8, L3=8*	*L1=7, L2=6, L3=9*

L1, L2, and L3 stand for Level 1, Level 2, Level 3, The pairs which are bold those whose curriculum materials were not classified in the same level along the five dimensions of analysis. PCK: Pedagogical content knowledge, IBL: Inquiry-based learning

student to formulate hypotheses through providing the general structure of a hypothesis, an example of hypothesis in another context and then the words that can be used for formulating the hypothesis. In addition, the teachers prompt the student to

Table 4: Activity sequence of Pair 10 clustered in Level 1 (transmissive curriculum orientation)

Orientation phase: Presentation of the scenario: "In ancient times, the transport and the commerce depended on shipbuilding. People should consider the materials to use for constructing a ship that would enable it to float in water"
Conceptualization phase: Formulation of the hypotheses and investigative questions by the student. The teachers provide to the student the general structure of them, an indicative example and the words that they can be used
Investigation phase: Design and conduction of two valid experiments based on teachers' guidelines (e.g., the teacher indicates which variable should be altered, which variables should be kept constant, and which variable should be measured)
Conclusion phase: The students are asked to draw their conclusion based on the emerged data. The teacher provides the anticipated conclusion and asks students to make any necessary modifications to their conclusion to make it compatible to the desired one

formulate investigative questions. In doing so, they provide the general structure of the investigative question "Does variable A affect variable B?" Examples of investigative questions, and predefined terms that can be combined to form the questions. In the investigation phase, the student is asked to design and perform two controlled experiments. Instead of giving the opportunity to the student to identify the variables involved in the experimental design, the teachers define the variable that has to be altered, the variable that has to be measured, and the rest of variables that have to be kept constant. The teachers also specify the materials and apparatus that would be used and the procedure that the student should follow to perform the experiment. To guarantee that student's conclusion would not decline from the anticipated one, the teachers provide a ready-made conclusion at the conclusion phase and prompt their student to compare his/her conclusion with the anticipated one to ensure that s/he will not leave the course with any misunderstandings or "wrong" conclusions.

Level 2 - Transmissive and transactive curriculum design orientation

This PDC level pertains to the case of curriculum designs that combined transmissive and transactive orientations. Specifically, the curriculum designs that were classified in Level 2 appertain to the type of curriculum design orientations that aim to engage their students in inquiry-oriented and conceptually driven activities, but at some point the teacher reduces students' autonomy in IBL, as s/he intervenes to showcase "what needs to be learnt" or/and how a procedure should be accomplished. We provide below a representative example of the activity sequence reflected in the ILS of Pair 3 (Table 5) to illustrate evidence of the combination of the transmissive and transactive orientation in their activity sequence and elaborate on it afterward.

In the beginning of the lesson, the teachers utilized the initial assessment tasks they designed to elicit their student's prior understanding about how a beam balance functions and the level of acquisition of inquiry skills. Then, they proceeded on providing a problem to their student that concerned the possible ways that the seesaw could balance. They guided their student to formulate investigative questions and hypotheses regarding the variables that affect the balancing of a seesaw, design and perform controlled experiments using a real balance for the purposes of experiment 1 and a virtual lab for the purposes of experiment 2. Afterward, they asked their student to draw conclusions based on the data collected and reflect on whether the data enable the confirmation or rejection of the initial hypotheses.

The above-mentioned activity sequence activity description reveals that the student has a central and active role in the inquiry process, given that teachers provide enough learning space for him to engage in multiple scientific practices associated with inquiry (e.g., hypothesis generation and testing, formulation of investigative questions, design and conduction of valid experiments, data collection and analysis, etc.), and thus the curriculum orientation so far points to a transactive perspective. However, after the investigation of the two factors - mass and distance - that affect the balance of a seesaw, the teachers decided that at this point the student should come to understand the concept of torque, and therefore they proceeded with the introduction of the rule that applies when the seesaw balances through a ready-made statement. Right after, they asked their student to implement this role in some examples (e.g., "On the right side there are four triangles (mass=2 g) on 4th position. On which positions on the left side would you place the three rings (mass=4 g) to balance the scale?"). Consequently, the transactive orientation that was evident from the beginning of the lesson and maintained up to this point was discarded and gave way to a transmissive orientation. Even though the activities that preceded could be used as the basis for helping the student define the rule himself through an inductive manner, the teachers assigned a passive role to their student through transmitting ready-made knowledge to him.

Level 3 - Transactive and transformative curriculum design orientation

The curriculum designs that were clustered in PDC Level 3 entailed activities that shared both a transactive and transformative orientation. These particular curriculum designs encompassed not only activities through which the students were supported in constructing their own learning, and the instructor acted as a facilitator during students' learning development but also activities that welcomed students' self-reflection, self-awareness, and self-learning. The teachers whose curriculum materials were clustered in this level aimed to prompt their students to elicit their existing knowledge about a topic under study, then they proceeded on helping students to confront their prior knowledge with knowledge that emerged through inquiry-oriented activities, and at the end they engaged the students in self-reflecting activities for reassessing the new knowledge in relation to their existing knowledge. We provide below an example of a pair of teachers' curriculum design in the context of Acids and Bases which was clustered in Level 3.

According to Table 6, at the beginning of the lesson, the teachers presented some pictures from a stream that the water was contaminated. Through a well-articulated scenario that they introduced to their student, they prompted their student to propose his ideas of how to test the quality of water, and in the subsequent activity, the student studied a report by the Ministry of Health that explained the methods followed for testing the quality of water. Through this report, the student became familiar with the concept of pH (the teachers incorporated a simplified definition of pH) and learnt that to decide if the water of a stream is contaminated, water samples from different locations of the stream should be collected and analyzed. In the conceptualization phase, the student familiarized himself with the concepts of acids and bases and subsequently formulated hypotheses and investigative questions based on the variables he identified that would affect the pH of a water sample. Using a virtual lab and physical manipulatives, he conducted experiments to test his hypotheses, answer his investigative questions, and draw conclusions. At the end of the activity sequence, the student reflected on the findings that emerged through answering questions such as "What are the real-life applications of acids and bases?" and "What could be the effects / consequences (positive and / or negative) of the use of acids and bases for you, others and society?" He was also asked to prepare a report that would be presented during the Science Fair day on the following topic: "To eliminate the phenomenon of acid rain, the use of cars in large urban centers should be reduced. What is your opinion."

The example presented above illustrates that the teachers acted as facilitators of student learning through the designed activities, as they systematically engaged their student in inquiry activities that enabled him to actively construct knowledge and develope skills necessary for solving the problem under study. Furthermore, the format and structure of the designed activities, which encouraged him to self-reflect on how the developed understandings about the topic under study (e.g., water contamination) associates with real-life problems, fostered the development of civic awareness.

Degree and type of reconstruction of the national curriculum unit

The second dimension of teachers' curriculum designs' analysis was the type and the degree of the national curriculum reconstruction they performed while designing their own curriculum materials. This task was accomplished through

Table 5: Activity sequence of Pair 3 clustered in Level 2 (transmissive and transactive curriculum design orientation)

Pre-test administration to elicit student's ideas about the concept of balance
Orientation phase: The teachers provide to the student the following scenario "Yesterday afternoon, two brothers, Costas and George, went to Athalassa's park and were playing at a seesaw. They observed that when Costas moved down, the seesaw went up at the highest point. The two kids are wondering about the possible ways that the seesaw could be balanced. Can you help them?" The student is prompted to express his ideas
Conceptualization phase: Formulation of the hypotheses and investigative questions by the student after the general structure of a hypothesis and an investigative question is provided. The student is encouraged to integrate the variables he assumed that might affect the balance of the seesaw in the hypothesis and investigative question
Investigation phase: Designing and Conduction of two valid experiments
The teachers provide the Experimental Design Tool on which the student is expected to decide the variable that should be tested, the variables that should be kept constant, and the variable that should be measured
The student organizes and conducts the experiments with the help of the teachers
The student reports the results on a table
The teachers introduce the principle of torque through a statement like "to make the seesaw balance, we need to calculate the product of the mass of the object that hangs on the lever, times the distance between the point of mass and the fulcrum. This should be done for each object on each side of the seesaw. The products should be equal when the seesaw balances"
The student follows the rule for calculating the product of each mass that hangs on each side of the seesaw times the distance between the point of mass and the fulcrum and confirms that the rule applies every time the seesaw balances
Conclusion phase: The student draws conclusions based on the data collected

Table 6: Activity sequence of Pair 17 clustered in Level 3 (transactive and transformative curriculum design orientation)

Orientation phase: The teacher provides to the student a problematic situation, and the student is prompted to propose solutions to the problem
Conceptualization phase:
Familiarization with the fundamental concepts of acids and bases
Formulation of the hypotheses and Investigative Questions by the student through appropriate scaffolding
Investigation phase:
The student organizes and conducts the experiments with the help of the teachers
The student reports the results on a table
Conclusion phase:
The student draws conclusions based on the data collected
Discussion phase: The student reflects on the relevance of processes and outcomes of inquiry for society

comparisons between teachers' curriculum designs with the corresponding national curriculum teaching materials. The three levels that were revealed as a result of the aforementioned comparisons are presented below.

Level 1- Replication of the national curriculum unit – modification only of the problem provided to students

This PDC level refers to the case of curriculum materials that were almost fully aligned with the existing activities of the national curriculum unit. Specifically, the examination of these curriculum materials revealed that the format, the structure, and the content of the activities of the national curriculum were maintained. The only changes that were performed concerned either the orientation phase, and specifically the type of problem that was modified to be more authentic and aligned with students' everyday experiences or the use of a limited number of apps/tools that were available in the grasp authoring environment.

The curriculum of the Pair 20, which was developed in the context of "Heat transfer and Thermal insulation materials," is an indicative example. We present in Table 7 the activity sequence mapping of the reconstructed unit of Pair 20 to showcase the degree and type of reconstruction followed for their curriculum development.

According to Table 7, the corresponding lesson of the national curriculum begins with a discussion about the possible variables that may affect the thermal insulation properties of different materials. The teachers of Pair 20 explained in their reflective journals that they considered this introduction as irrelevant to students' everyday lives and thus they proceeded on modifying the introduction by adding a case-based problem to be make the orientation phase more authentic and relevant to students' lives. Furthermore, a small modification was also performed in activity 4 (Table 7 for details), as teachers substituted the use of a table for making records of the values of the variables that relate to the experimental design with the use of the Experimental Design Tool, an app that is available for use in the Go-Lab platform and facilitates the design of valid experiments for answering the investigative questions that are previously followed.

Level 2 - Partial reconstruction of the national curriculum unit – design of extra inquiry activities

The curriculum designs that were clustered in PDC Level 2 concern the case of national curriculum materials that were modified and enriched by the addition of extra inquiry activities that were incorporated effectively into the existing activity sequence. The curriculum materials of Pair 1, which were built in the context of "Friction" is an indicative example of curriculum designs that were categorized in Level 2. As illustrated in Table 8, the existing activities of the national curriculum unit are an inquiry-oriented as they engage students in several scientific practices such as formulation of investigative questions, designing and conduction of valid experiments, and reporting of findings. In looking at the activity sequence developed and implemented by Pair 1, it is noticeable that the teachers enriched the national curriculum materials with more inquiry activities that offer extended learning opportunities to their student. In particular, the teachers chose to change the problem to make it more authentic and compatible to student's everyday life, and they also added an extra activity that pertained on asking the student to define the problem to verify that the problem at hand was comprehended by the student and that the student appreciated the need for finding a solution to the problem. Furthermore, they embedded activities through which the student would be introduced to new concepts and terminology, such as smooth and rough surfaces. These new concepts served as facilitators in helping the student to identify possible variables that might affect the friction exerted on a surface when an object is rubbed on it, and integrate them, at a later stage, in investigative questions, and hypotheses that could be tested through the design and conduction of valid experiments. Furthermore, this pair of teachers integrated some activities through which student's active role in the implementation of the inquiry activities is highlighted and promoted. For instance, during the experimentation phase they prompted their student not only to merely stating the variables that should be altered, measured, and controlled but also to decide how to alter the independent variable (e.g., I would use three different carpets that differ in roughness), how to measure the depended variable (e.g., by

Table 7: Activity sequence of Pair 20 clustered in Level 1

National curriculum activity sequence	Activity sequence of Pair 20
The teacher asks the students: Which factors affect the thermal insulation properties of different materials?	The teacher asks the students: "Mr. Brown uses a coffee pot to prepare coffee for his customers every day. What type of material the handle of the coffee pot should be made of to prevent his hand from burning?
The students discuss and write down possible factors	The students discuss and write down possible factors
The students formulate investigation questions. The teacher gives them the general form of it	The students discuss and write down possible factors. The teacher gives them the general form of it
The students design and perform their experiments and record their measurements. They are provided with a table on which they have to define the variable that should be tested, the variables that should be kept constant, and the variable that should be measured	The students design and perform their experiments and record their measurements. They are provided with the Experimental Design Tool on which they have to define the variable that should be tested, the variables that should be kept constant, and the variable that should be measured
The students draw their conclusions	The students draw their conclusions

The activities in gray-colored boxes corresponds to the new activities that the Pair 20 designed and incorporated in its curriculum material. The activities in white colored boxes represent the activities that were replicated from the national curriculum unit without any changes

Table 8: Activity sequence of Pair 1 clustered in Level 2

National curriculum activity sequence	Activity sequence of Pair 1
Introduction to a scenario to stimulate students' curiosity and to orientate to the problem. "Aris enjoying slipping on snow. He wants to make a board to be able to move as far as possible after he get off the slope	Introduction to a scenario to stimulate students' curiosity and to orientate to the problem. "In recent months, a housewife has been complaining that her new shoes do not help her at all when she is mopping the floor, because she slips"
	Students state the problem situation
	Students are introduced in concepts and terminology (e.g., smooth, rough surface)
Students formulate an investigative question	Students formulate investigative questions, hypotheses, and predictions
Students complete a table to design their experiment	Students use the Experimental Design Tool to design their experiment
Students choose among a given list of variables of the variable that is going to be altered, the variable that is going to be measured, and the variables that will be kept constant	
	Decide about which variables are going to be altered, kept constant, and measured
	Students decide about the materials they are needed for performing their experiment
	Students make a graph to plot the data collected and reflect on the relationship that is revealed between the variables
Students make a presentation to share their findings	Students report their findings of their experiments in a table
	Students write the conclusion and reflect on the inquiry process

The activities in dark gray boxes correspond to the new activities that Pair 1 designed and incorporated in their curriculum materials. The activities in light gray color relate to these which were partially reconstructed from the national curriculum unit

measuring the friction exerted on an object that rolls on each carpet; the more the object rolls on a particular carpet the less the friction is), and how to control (keep them constant) the rest of the variables that are involved in the experiment (e.g., I would use the same object in each trial, the starting point when the object rolls in each carpet would be the same, etc.) (Note: The statements in parentheses pertain to student's quotes, as these were captured and integrated in teachers' reflective journals). In addition, they engaged their student in creating a graph with the use of the data collected during experimentation. Through this activity, their student was expected to identify the relationship between the depended and independent variables based on the type of graph that would emerge after the plotting of the data, and thus to draw conclusions about how the variables under study are related.

Overall, the activity sequence presented above indicates that the teachers who were clustered in Level 2 performed a partial reconstruction of the activities of the national curriculum unit to make the existing activities more authentic and more student-centered, and enrich them with activities that fostered their students' engagement in fundamental scientific practices centered on inquiry.

Level 3 - Total reconstruction of the national curriculum unit with strong priority to IBL

PDC Level 3 encompasses the curriculum materials whose designers followed a total reconstruction of the national curriculum unit they chose to work with. To showcase the type of reconstruction that has been applied to these curriculum materials, we selected the curriculum materials of Pair 19 as a representative example.

Pair 19 reconstructed the unit "Forces and Motion" from the national curriculum. As these teachers explained in the documentation provided in their reflective journals, the purpose behind proceeding in a total redesign of the existing curriculum materials departed after examining the existing curriculum materials and concluding that inquiry was almost absent from the entire unit. Hence, through their proposal of how this particular unit should look like, they stated that they would seek to assist their student in formulating operational definitions about the concept of force through a constructivist and inquiry-oriented approach. This would be accomplished through investigating the factors that would affect the relocation of an object. Table 9 summarizes the structure and the content of the activities of the national curriculum unit in conjunction with the activities of teachers' curriculum materials.

According to the Table 9, it appears that in the activity sequence of the national curriculum the students neither are engaged in developing hypotheses or investigative questions about the phenomena under study nor are encouraged to design and perform any controlled experiments and, as a result, they do not experience inquiry learning at all. On the contrary, the activity sequence proposed by Pair 19 illustrates a total reconstruction of the existing curriculum materials and most importantly, the inquiry activities that were designed aim to help the student develop inquiry skills and conceptual understanding of the phenomenon under study. The teachers focused not only on aimed to help the student define the concept of force in the context of the activities he engaged with but also to integrate the developed concept into the inquiry cycle.

Table 9: Activity sequence of Pair 19 clustered in Level 3

National curriculum activity sequence	Activity sequence of Pair 19
Students are asked to relocate an object on their desk to identify how this task can be accomplished	Orientation phase: Presentation of the scenario concerning two kids who are playing tug of war. They are exerting force on the rope in opposite directions. The winner is the kid who will push the other toward him. The students are prompted to state what the kids should do to win
Students explain the different ways they followed in solving the task using the words: Push, pull, force, location	Conceptualization phase: Students are asked to define the concept of force based on their experiences. They formulate investigative questions and hypotheses
Students observe a set of images that show kids pushing or pulling or both different objects. They discuss how the force is acting on the objects in each case	Investigation phase: Students decide the materials that will be used. They use the Experimental Design Tool to design their experiment (they identify the variables that will be altered, kept constant, and measured and propose how these will be manipulated in the context of their experiments)
Students are provided with a definition of force	Students perform their experiments
Students are introduced in a problem: The capacity of the school bin is very law, so there is not enough space for the plastic bottles of water. What the school students could do?	Students plot the data collected in graphs with the use of the Graph tool and formulate conclusions about the relationship between the variables that have been tested
They conduct an experiment in which they apply force on a plastic bottle and note their observations	Students revisit their investigative questions to pose answers and confirm/reject the associated hypotheses
Students formulate a conclusion based on the experimental data collected	Students transfer the newly acquired knowledge in new contexts
They read the following scenario: Two kids saw a very heavy box of books at the entrance of the class. They thought that it has to be moved, but it's so heavy!	
They conduct an experiment and conclude that a force can change the direction of an object	

Types of the designed activities

With regard to the third dimension of curriculum materials analysis, the analysis of teachers' ILSs revealed that the type of activities that were incorporated within their ILSs were mainly inquiry-oriented, conceptually driven, and were interconnected in some cases with scaffolds that were used to foster students' inquiry competence and conceptual understanding. However, the level of learners' autonomy when following the designed inquiry activities, the format of the conceptually driven activities, in conjunction with the presence and location of scaffolds along the activity sequence, enabled the classification of teachers' activities into three distinct PDC levels that are presented below.

Level 1 – Very structured inquiry activities - Conceptual understanding development is either missing or accomplished through delivery of ready-made statements - Partial scaffolding

PDC Level 1 entails teachers' curriculum materials that entailed very structured inquiry activities. Whenever teachers attempted to involve their students in inquiry-oriented activities, this was accomplished through a cookbook-like procedure (e.g., first do this, then do that …). Furthermore, the lack of activities that intend to foster students' development of conceptual understanding across the curriculum designates that teachers of Level 1 did not give emphasis to this particular learning dimension. The description of the activity sequence of Pair 22 in the context of electromagnetism is particularly revealing in documenting the abovementioned findings.

In the orientation phase, the students construct an electromagnet with the guidance of the teachers. Afterward, the teachers provide to students a text that explains what an electromagnet is and where electromagnets are used. In the conceptualization phase, the investigative questions "Does the size of the magnet affect the magnetic attraction force?" and "Do the number of turns in the coil affect the magnetic attraction force?" are delivered as ready-made to the student. In addition, the corresponding hypotheses are also delivered in a ready-made manner, and the student is asked to change the given hypothesis in case she disagrees with the relationship of the variables that were assumed and integrated into a specific hypothesis. In the next phase, the teachers do not prompt their student to propose an experimental design of how to test the hypotheses or respond to the investigative questions. Instead, the experimental design is given as a narrative to the student (e.g., in our experiment we need to vary the number of turns in the coil variable; hence we need to decide how many turns are needed in each experimental trial…), and the student is asked to use the experimental design tool to define the values of the variable that had to be altered and the values of the variables that should be controlled (Figure 1). After conducting a specific experiment with the use of an Online Lab, the student is asked to fill in a table with the conclusions derive from the data collected. This activity, albeit important for facilitating student's conceptual understanding, it is "served" to a student without any conceptual scaffolding (e.g., What do the data collected tell us about the relationship between the tested variable and its impact on electromagnetic force?).

In summary, the curriculum materials that were clustered in Level 1 share a teacher-directed teaching approach, as the teacher is the one who defines the steps for when and how inquiry activities should be implemented. As far as the conceptual understanding and scaffolding are concerned, this is also accomplished either through lecturing or through content delivery statements, since students are seldom prompted to

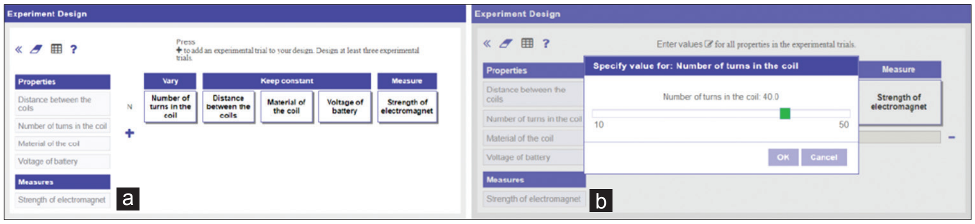

Figure 1: (a) Illustrates how the experimental design was prepared by the teachers, (b) illustrates how the student altered the number of turns in the coil

appreciate the need for articulating operational definitions for the concepts involved in the context of their investigation.

Level 2 – Structured and guided inquiry activities - Introduction of concepts through examples from everyday life – Conceptual and procedural scaffolding

Teachers' curriculum materials that were clustered in PDC Level 2 involve structured and guided inquiry activities, as well as activities that promote the familiarization with concepts through examples from everyday life. However, the teacher still remains in the forefront and the student act as a follower of his/her predefined learning pathways, since whatever students are expected to learn or do in the context of the lesson is prescribed by the teacher, either directly or through the curriculum materials s/he designed. The curriculum design of teachers of Pair 4 in the context of Light and Shadows is an indicative example that falls in Level 2. We briefly describe below the format and structure of their activity sequence for documenting the clustering of their curriculum materials in Level 2.

First, the teachers introduce a problem regarding the factors that affect the size of a shadow. This was as follows: "It's 8 o'clock in the evening and Petros is waiting at the bus stop to catch the bus for home. On the left side of the bus stop there is a floor lamp. Petros noticed that his shadow is formed on the opposite wall, and was surprised to notice that his shadow increased or decreased whenever he approached or moved backward to the wall. Why is this happening? Can you help him understand this phenomenon?" Next, the teachers prompt the students to go out, observe their shadow, and explain why and how a shadow is formed. After stating their thoughts, the teacher presents the following piece of text "A shadow is formed when light from a source is blocked by a solid object. The shadow is the dark area formed behind the object. The object should be opaque or translucent for shadow formation because light cannot travel through such material. A transparent object cannot create any shadow because the light will pass straight through it." After introducing the shadow concept, the teacher provides guidance to the student to formulate investigative questions and hypotheses and subsequently proceeds in designing a controlled experiment to test each hypothesis. The teachers through the curriculum provide all the variables involved in each experimental design and the student is prompted to decide the variables that will be altered, measured, and kept constant according to the investigative questions and hypotheses. Then, he performs the experiments with the use of the Online Lab, organizes the data in a predefined table, and following the teachers' guidelines (e.g., Which variable should be placed in the horizontal axis? Which on the vertical axis?) he creates a graph with the use of the Graphing Tool to study the relationship between the variables under study. At the end of the activity, the student is asked to answer the investigative questions and reject or confirm the hypotheses developed during the orientation phase through writing a report. The aforementioned scaffolds are provided during both investigations and do not gradually faint out as the student moves from the first inquiry cycle to the second.

To sum up, the designed activities were mostly guided inquiry-oriented. The student, on the one hand, receives support from the teachers either through prompts for reflection or through text that entailed ready-made knowledge (e.g., the definition of a shadow), and on the other hand, the student is given the opportunity to investigate himself the impact of two independent variables on a dependent variable, collect and analyze data, and make reports about the yielded findings.

Level 3 – Guided and open inquiry activities - Conceptually oriented activities interconnected with the inquiry activities - Conceptual and procedural scaffolding that faints out gradually

PDC Level 3 includes the case of curriculum materials that were developed on the tenets of a combination of guided and open inquiry perspective. A balance of both inquiry and conceptually oriented activities was evidenced, and most importantly, these activities were well interconnected as the inquiry activities complemented the conceptually oriented activities and vice versa. To foster learners' engagement in both types of activities, several conceptual and procedural scaffolds were designed and embedded at several instances in the activity sequence, and these scaffolds appear to faint out gradually as learners move from the initial inquiry cycle to the later one. The curriculum materials of Pair 8 that was designed in the context of "Sinking and Floating" is a representative example of a curriculum clustered in Level 3 and is briefly presented below.

In the beginning of the lesson, the teachers introduce an authentic scenario to their student, in the context of which a problem emerges. In the conceptualization phase, they engage their student in the development of an operational definition for the concepts "sinking" and "floating." Specifically, they provide a piece of aluminum foil to the student and prompt her to place it first on the surface of the water of a water basin and record her observation (the aluminum foil floats this time). Next, the student is prompted to place the aluminum foil inside the water basin and observe what would happen (the aluminum foil sinks this time). Based on these contradictory observations, the teachers highlight the importance of deciding how and where to place an object inside a water basin to decide if it will float or sink. They decide mutually with their student that the best way is to place the object inside the water basin and observe what would happen. In case the object moves to the bottom of the basin, this means that the object sinks. On the contrary, if the object moves toward the water surface, this means that the object floats. Through this constructivist approach, the student is guided to formulate an operational definition of sinking and floating that is going to systematically use it during the investigations that follow.

In the subsequent activities, the student is involved in two inquiry cycles. During the first inquiry cycle, the student is guided on how to formulate an investigative question and a hypothesis. To scaffold these tasks, the teachers provide her with the general form of an investigative question (e.g., Does variable A affect variable B?) and the student is prompted to use this syntax for formulating the investigative question in the context under study. In the case of hypothesis generation, the teachers explain that hypothesis should entail a relationship of how two variables are assumed to be associated with (e.g., the more the… the more (or the less) the …) and ask student to use the investigative question as the basis for defining how variable A will affect variable B and through this a hypothesis would be formulated. Next, the student proceeds with the design of the first experiment and asked about how to manipulate the variables involved in the experimental design (e.g., what variable should be altered and how is going to be altered, and so on). After finishing with the experimental design, the student uses an Online Lab in the context of sinking and floating to conduct the experiment she previously designed, collects data, and record them on a table. The teachers act as facilitators of the data collection and organization on the table through prompts and scaffolds (e.g., in the first column you need to enter the values of the independent variable, in the second column the values of the dependent variable, etc.).

As soon as the student finalizes the data collection, analysis, and reporting the findings (first inquiry cycle), she proceeds with the second inquiry cycle. It is important to note at this stage that during the entire second inquiry cycle, the teachers let the student alone to formulate an investigative question and a hypothesis, and decide about the variables that should change, measure, and keep constant. Then, the student decides on her own the procedure for conducting the experiment, what data should be collected, how the data would be analyzed and reported, and so on. Although no scaffold is provided, the only guidance that is offered to the student is a reminder; if she does not recall how to perform a specific practice, she needs to revisit the first inquiry cycle and refresh of how this was done. Hence, it appears that the scaffolds faint out as the student transitions from the first inquiry cycle to the second, in case there is enough evidence that the student can take over the process of the inquiry learning.

Integration of the inquiry learning cycle within the curriculum designs

One of the requirements that were included among the guidelines provided to teachers when designing their curriculum materials points to the learning objectives that should be promoted through the learning activities they were expected to design and implement with their student. Specifically, the teachers were expected to design inquiry activities through which they would help their student develop inquiry competence (e.g., inquiry skills and epistemic understanding about the nature and purpose of inquiry). To address this learning requirement into their curriculum designs, they had to exploit the principles of IBL and follow the phases of inquiry learning framework they went through as learners in Phase 1 and built on its tenets that were inductively identified during Phase 2 of the PDP (see Methods section for more details).

Three levels of increased sophistication yielded from the examination of their curriculum designs in terms of how the inquiry was articulated into their curriculum designs and approached afterward during their practice.

Level 1 – Inquiry as a linear process

PDC Level 1 relates to curriculum designs that approached the inquiry components in a linear fashion. An indicative example that is briefly described below is the curriculum design of Pair 2.

The teachers followed a linear process while designing and implementing their inquiry activities that were compatible with the process found in many science textbooks (i.e., question, hypothesis, experiment, results, and conclusion). The teachers begin with a video that presents four primary students performing an experiment to confirm or reject the Aristotle's hypothesis "Heavier objects fall down more quickly than light objects in a vacuum." The students at the video present the process of how to conduct the related experiment, mention their findings, reject the Aristotle's hypothesis, and formulate a new hypothesis as follows "All objects reach the ground at the same time when left to free fall from the same height in a vacuum." This hypothesis is used by the student as the starting point for the investigation that follows. Specifically, the teachers ask the student to decide about the object that will be used, what variables should be kept constant, and how to measure the time of flight of the objects. As soon as the experiment is conducted and the student has already collected enough data, he proceeds in drawing the main conclusion.

The activity sequence example shows that the student followed a straightforward process where the phases of inquiry appear in a series manner. For instance, in the investigation phase, the student could be asked to move back to the orientation phase to compare his findings with the findings that were presented in the video. Furthermore, at the end of the process, the student could go back the conceptualization phase to retrieve the initial hypothesis and decide of whether it could be confirmed or rejected based on the collected data. Overall, it seems that these teachers believe that scientific knowledge is generated in a single, fixed manner, and that inquiry is carried out in linear and sequential steps.

Level 2 – Inquiry as a linear process but sometimes students are prompted to back to recall what has been done or learnt

PDC Level 2 pertains to teachers' curriculum materials that again inquiry was assumed to be a linear and straightforward process. The difference between this level and the previous one lies in the fact that in Level 2 there was evidence of instances where teachers prompted the students to go back to recall what has been done or learnt. A representative example of Level 2 curriculum designs is the one developed by Pair 7 in the context of hydrostatic pressure.

The activity sequence begins with the orientation phase during which the student watched a video about a diver who wondered what will happen if a sealed plastic bottle full of air dives at 10-meter depth in the sea. The video illustrated a plastic sealed bottle that was compressed at the 10-meter depth in sea water because of the hydrostatic pressure exerted on it. When the diver released it to the surface of the water, the bottle was decompressed and returned to its normal shape. After this introduction, the student identified possible variables that might affect hydrostatic pressure. In the next phase, the student chose two of the identified variables and prompted to formulate investigative questions and the corresponding hypotheses. At the beginning of the investigation phase, the teachers informed the student that he would use the hydrostatic pressure virtual laboratory for conducting the experiments to collect experimental data to confirm or reject his hypotheses. The curriculum proceeds with an illustration of the virtual lab and its capabilities. When it was time for conducting the experiments to test the previously developed hypotheses, the student was asked to go back to the conceptualization phase to recall the hypotheses developed to choose the appropriate variables for conducting the related experiment. In the conclusion phase, the student drew conclusions based on the data collected during the preceding phase. At this point, the teachers asked the student to recall the video that was presented during the orientation phase and provide an explanation to account for the plastic bottle decompression under the water.

The abovementioned activity sequence designates that the teachers assumed that inquiry is organized into a set of consecutive phases that are linked in a linear manner. The purpose behind prompting the student to revisit a previous phase was to help the student recall something that was previously stated and not because the inquiry was assumed as a cyclical and iterative process.

Level 3 –Inquiry as a cyclical and iterative process

The curriculum materials that fall into PDC Level 3 were designed according to the IBL framework suggested by Pedaste et al. (2015). More specifically, the inquiry activities that were incorporated in the curriculum materials were organized in a cyclical and iterative manner. To present how an activity sequence clustered in Level 3 looked like, a description of the curriculum materials of Pair 12 is provided below.

In the orientation phase, teachers, the teachers provided the following scenario: "George visited his grandmother and forgot his glasses at home. He wanted to watch his favorite TV series, but it was impossible to watch it without his glasses. Hence, he thought of using his grandmother's glasses. When he tried to watch on TV, everything was blurred! He started wondering why the glasses of his grandmother caused such an effect." In the conceptualization phase, the student became familiar with the different types of lenses. Furthermore, the student formulated the first investigative question and the hypothesis concerning the impact of "type of the lens" on the "clarity of an image." In the investigation phase, the student performed a controlled experiment, collected evidence to answer the research question, and represented the data in a table and a graph. After the first investigation, the student returned to the conceptualization phase to formulate a second investigative question and an associated hypothesis that both related to the impact of the "thickness of a lens" on the "clarity of an image." As a follow-up activity, he was asked to design and conduct a valid experiment, record the data, and create a graph. In the conclusion phase, the learner revisited the investigative questions and the hypotheses and drew conclusions based on the data collected. Specifically, he utilized the data to respond to the investigative questions and rejected or confirmed the hypotheses. Furthermore, at this stage, the learner returned to the initial problem (why he could not see clearly when used his grandmother's glasses) and tried to solve it through applying the newly acquired knowledge.

Organizing the activity sequence in two consecutive inquiry cycles, as illustrated in the abovementioned extract, designates that teachers whose curriculum materials were clustered in Level 3 conceptualized inquiry as an iterative process that involves several phases that are interconnected in a cyclical manner. This conceptualization is totally different compared to the conceptualizations of teachers in Levels 1 and 2, as these conceptualized inquiry as a prescribed, uniformed and linear process.

Evaluation of students' learning gains

The last dimension that was used to analyze teachers' curriculum materials were examined concerned the assessment tasks they developed to evaluate their students' learning gains. Specifically, the type, the format, the content, and the time of administration of the assessment tasks were taken into consideration while looking at the means of evaluation of students' learning gains. Three levels of increased sophistication emerged from the analysis and are presented below.

Level 1 – Pre- or post-evaluation of students' rote learning through closed-ended questions

This PDC level concerns teachers who designed only pre- or post-evaluation tasks for assessing students' declarative knowledge related to the subject domain of their ILS. The assessment was carried out before or after the implementation of their ILS and the format of the tasks they designed were in the form of multiple choice questions or/and true/false questions or/and closed-ended questions. It is important to note that no tasks were designed to assess students' inquiry skills. The assessment task designed by Pair 6 is an indicative example and is presented in Figure 2.

According to Figure 2, this pair of teachers chose to evaluate students' understanding of the concept of Friction in the format of a multiple-choice question. Furthermore, this assessment task was administered only at the end of the curriculum's implementation. It should be pointed out that this assessment task measures if the students were able to recall something that was already been discussed during their engagement with the ILS. Specifically, right after they finished investigating factors that relate with the context of friction, the teachers introduced some scenarios from individuals' everyday activities that friction is involved, and students were asked to study the scenarios and tell whether friction facilitated or impeded the task performed by individuals. The case of using chains on a car's wheels on a slippery road was among the scenarios administered to students. Given that teachers chose a context that their students had already been introduced in the context of the ILS implementation to assess their conceptual understanding status, it was concluded that the emphasis of the assessment related to rote learning.

Level 2 – Pre- and post-evaluation of students' understandings about concepts relevant to the topic engaged with open-ended tasks

Level 2 relates to the case of students' assessment in the beginning and ends of the ILS implementation and focused on students' understandings about concepts relevant to the topic engaged. Open-ended tasks were designed that prompted students' to provide the reasoning behind their responses. An example of two assessment tasks developed by Pair 16 is provided in Figure 3 and elaborated afterward.

The assessment tasks presented in Figure 3 concern two assessment tasks that were administered at the beginning (pre-test) and end (post-test) of ILS implementation. Through the pre-test, the teachers aimed to evaluate their student's prior ideas whether a specific factor (e.g., mass of object attached to a vertical spring) affects the elongation of a spring. In their reflective journals, the teachers explained that it was important for them to know their student's initial ideas to design the intervention in the context of "forces and springs" in a way that it would be meaningful to their student. As a post-test assessment task, the teachers designed a different task to assess the same learning objective as the pre-test (e.g., whether the mass of an object attached to a vertical spring affects its elongation, see post-test in Figure 3 for more information). The rationale behind designing this task was based on the assumption (according to teachers' explanation found in their reflective journals) that post-test assessment should be accomplished through tasks that welcome students' ability to transfer their developed understandings and knowledge in contexts near or far of the context of instruction.

Level 3 – Pre- ongoing and post-evaluation of students' inquiry skills and understandings about concepts relevant to the topic engaged with open-ended tasks

PDC Level 3 resembles PDC Level 2 in that it entails the case of assessment tasks that focused on evaluating students' conceptual understanding, but it also encompasses assessment tasks that pertain in evaluating students' inquiry skills. This was accomplished through several tasks they designed and administered throughout their intervention. A noteworthy feature of these assessment tasks relates to the context chosen for designing these tasks. Specifically, the teachers chose not only the context of their ILS but also different contexts, because (according to their own words) "It is important to see if students are able to transfer these skills in new domains. If they can do this effectively, then we can be sure that they truly developed the inquiry skills we helped them to develop" (extract from Pair 14 reflective journal).

Another significant characteristic of Level 3 that differentiates from Level 2 concerns the chronological order of assessment implementation that was accomplished not only through pre- and post-tests but also through ongoing assessment tasks. A representative example of an evaluation task designed by Pair 14 to assess students' inquiry skills is provided in Figure 4.

As illustrated in Figure 4, the teachers designed an assessment task in the context of pendulums, through which they aimed at examining whether their student is able to identify flaws in a given experimental design and resolving these issues through proposing a controlled experiment. The teachers

Read the following statement and choose the correct answer. Put a tick in the appropriate box:

When we drive on ice, we place chains on the wheels of the car to:

a) increase the friction
b) decrease the friction
c) the friction remains constant
d) none of the above

Figure 2: Excerpt of the assessment tasks of Pair 6 in the context of friction

Pre-test
1.Michael argues that a vertical spring elongates the same whenever objects of different mass are attached to it.Do you agree with Michael's argument ? Explain your response.

Post-test
2. Imagine you are going to participate in a Science Fair and the challenge is to design a device to measure the mass of different objects. You are given the following materials:

- a plastic tube that contains inside a spring. There is a hook at one of the ends of the spring,
- a pen marker,
- a ruler,
- a set of 10 metallic nuts each of which weighs 100 gr

Make a drawing of the proposed device, describe how you constructed it, and how one can use it to measure the mass of an object.

Figure 3: Excerpt of the assessment tasks of Pair 16 in the context of springs

> Myrto wants to study if the mass of a weight influences the time it takes to cover the distance A to B and vice versa (in the context of a simple pendulum). The first time she placed a weight of 30g in the shape of a wooden sphere and the second time she placed a weight of 40g in the shape of a plastic cube. Is the experiment valid? How would you correct the design of this experiment in order to be valid?
>
> Justify your answer.

Figure 4: Excerpt of the assessment tasks of Pair 14 in the context of simple pendulum

did not focus on the assessment of student's knowledge of what a "controlled" experiment is, but instead, they aimed at giving the opportunity to their student to apply the skills and knowledge he developed in the context of ILS implementation in a new context.

Classification of pairs of teachers' curriculum designs in the emerged levels across the five PCK for IBL dimensions

The distribution of the 22 pairs of teachers along the five dimensions of analysis of their curriculum materials and across the emerged PDC levels are presented in Table 3. According to the findings of Table 3, it appears that the majority of the pairs of teachers (17 out of 22) revealed a consistency in the degree of sophistication of their curriculum designs. These pairs were classified as follows; six in Level 1, seven in Level 2, and nine in Level 3.

The five remaining pairs of teachers' curriculum designs were not classified in the same emerged level across the five dimensions of analysis. Specifically, the curriculum materials of Pair 1, Pair 7, and Pair 18 were classified in Level 2 in all dimensions except for the Evaluation of students' learning gains (pair 1), the Types of the designed activities (pair 7), and the Degree and type of reconstruction of the national curriculum unit (pair 18). Pairs 17 and 12 were categorized in Level 3 except for the dimensions integration of the inquiry learning cycle within their curriculum designs (Pair 17) and teachers' curriculum design orientation and types of the designed activities (pair 12).

Nevertheless, the frequency of teachers' classification along the three levels of increased sophistication resulted from the analysis of their curriculum materials, in conjunction with the degree of consistency within each emerged level; suggest that teachers who engaged in the same PDP for IBL have conceptualized in diverse ways the underlying principles of the IBL approach.

What Information Do The Characteristics of Preservice Teachers' IBL Curriculum Materials Provide Concerning Their PCK for IBL?

Looking closely at the characteristics that emerged for every level and for each of the five dimensions of analysis, we gain insights not only of the status of teachers' PDC for IBL but also the amalgamation of these aspects helps in portraying teachers' PCK for IBL. An examination of the characteristics within each of the emerged levels revealed three different profiles of teachers' PCK for IBL which are elaborated below.

Profile A

The teachers with profile A choose to take up a teacher-directed orientation in their curriculum designs. The activities they designed are characterized by strong transmissive pedagogies; they seem to entirely control students' learning and expect that the pieces of knowledge they diffuse through their lessons will be "absorbed" and "recycled" by their students when in need. This claim is enhanced through the absence of activities that would help their students develop inquiry skills that are necessary to be applied for the study of future scientific phenomena. In addition, these teachers show a strong attachment to the textbooks used at schools, since the teaching materials they develop do not deviate much from the activities included in the national curriculum units. As a result, they keep intact the format, the structure, and the content of the national curriculum activities.

As far as the types of the designed activities are concerned, they design or select from the textbooks very structured inquiry activities, as these resemble a cookbook-like procedure. This particular perspective they adopt can be attributed to how these teachers conceptualized inquiry in terms of its format and its purpose. The way they structured the inquiry activities they designed, designates that they assume inquiry to be carried out in linear and sequential steps, and, also, scientific knowledge is produced in a single, predetermined approach.

Similarly, when it comes to conceptual understanding and its associated scaffolding, this is also accomplished either through lecturing or through content delivery statements, since students seldom are prompted to appreciate the need for articulating operational definitions for the concepts involved in the context of their investigation. Given that their curriculum materials do not entail activities that intend to foster and monitor students' development of conceptual understanding, it appears that teachers with profile A do not attend to this particular learning need of their students.

Finally, the type and format of assessment tasks they propose to use for capturing students' learning gains reveal a favor to rote learning, since they do not attempt to challenge their students in transferring the newly acquired knowledge into new domains.

Profile B

The teachers who adopt this PCK profile implement both transmissive and transactive curriculum design orientations in their curriculum materials. Although they show an interest in engaging their students in inquiry-oriented and conceptually driven activities, and thus to provide them with necessary space for active knowledge construction, at some point they reduce students' autonomy in IBL, as they intervene to illustrate "what needs to be learnt" or/and how a procedure should be accomplished.

During working with their inquiry designs, they proceed in the partial reconstruction of the format, the structure, and the content of the unit from the national curriculum. Through their designs, they aim at making the activity sequence more authentic and student-centered, foster students' familiarization with concepts through introducing examples from everyday life, and give substantial emphasis to students' engagement with fundamental scientific practices centered on inquiry. However, because they still do not feel confident enough to let their students follow their own learning pathways when practicing inquiry, they remain in the forefront to ensure that their students will not decline from what they have already planned to be learnt and how to be learnt. Since they feel insecure to "mess up" when having their students working in an autonomous manner, they organize the inquiry activity sequence into a set of consecutive phases that are linked in a linear manner. They might allow their students to move back and forth while progressing from one inquiry phase to another, only if the students need to recall something that was previously stated or learnt. Hence, they appear to have conceptualized inquiry not as a cyclical and iterative process, but instead as a linear one.

When it comes to assessing their students' learning gains, they do not seek to explore whether their students have developed any inquiry skills. Instead, the emphasis of their assessment concerns only students' development of conceptual understanding. Their evaluation is implemented both at the beginning and end of their instruction, and it is accomplished through open-ended tasks that welcome students' expressing the reasoning behind their responses.

Profile C

The teachers who correspond to this PCK profile integrate a combination of transactive and transformative orientations when designing their IBL curriculum materials. Given that they consider their students and themselves as actors in leading and supportive roles, respectively, they systematically scaffold their students to actively constructing their own learning through activities that promote self-reflection and self-awareness. In doing so, they prompt their students to express their ideas about a topic under study, then they challenge them to confront these ideas with the knowledge that emerges through inquiry-oriented activities and at the end, they scaffold them in enriching, revising, or reconstructing their existing knowledge.

Their curriculum materials are developed on the grounds of a combination of guided and open inquiry perspective and give strong priority in helping their students to develop inquiry skills and conceptual understanding of the phenomenon under study. To succeed in this direction, a well balance of both inquiry and conceptually oriented activities exists within their curriculum designs that are interconnected in a way that the inquiry activities complement the conceptually oriented ones and vice versa. To facilitate their students' meaningful engagement in both types of activities, they integrate several conceptual and procedural scaffolds in the activity sequence, and they choose to faint them out once they feel that their students have mastered what is expected to be learnt to transit through inquiry cycles. As a result, these teachers appear to have conceptualized inquiry as an iterative process that involves several phases that are interconnected in a cyclical manner.

As far as the evaluation of students' learning gains is concerned, this is accomplished through several assessment tasks that are used as an initial, ongoing, and final evaluation of students' status of inquiry skills and conceptual understanding. To ensure that their students have comprehended the anticipated concepts or developed the inquiry skills that are fostered throughout the IBL activity sequence, they design assessment tasks that require students to meaningfully apply the concepts and skills they might have mastered in new domains.

DISCUSSION AND CONCLUSIONS

The study aimed at examining preservice elementary teachers' inquiry-oriented curriculum materials in an attempt to unravel their PDC and PCK for IBL, after attending our specially designed PDP, and centered around inquiry-based teaching and learning. The analysis of teachers' curriculum materials revealed that they were developed along five PCK for IBL dimensions. In terms of the characteristics of the teachers' IBL curriculum materials, our analysis revealed three levels of increased sophistication along each of the five dimensions. Each of these levels corresponded to a different teacher PDC. Moreover, through our data analyses, we managed to identify three different PCK for IBL profiles.

The combination of all these findings provides an interesting background which might prove valuable in understanding how an effective PDP must be designed. First, we should highlight the contribution of the teachers' curriculum materials as means for studying teachers' PDC and PCK for IBL. In prior research, the types of teachers' knowledge transformations were elicited either through written questionnaires, clinical interviews or class observations (e.g., Elster et al., 2014; Seraphin et al., 2013). In this study, we made use of teachers' curriculum materials as a lens to examine these transformations and managed to collect considerable evidence about the status of their PCK and PDC. This approach is in line with the stance of Beyer and Davis (2012), who argue that looking into teachers' curricular planning practices we can gain insight on the types of knowledge that teachers employ in their planning and the ways in which they apply the different types of knowledge in their own practice.

Second, the findings of the study showed that our preservice teachers entered our PDP with all sorts of background differences, which resulted in having the teachers perceiving the content of the PDP in a different manner. We inferred this from the different characteristics of their IBL curriculum materials, the different levels of their PDC and the different profiles of their PCK. Therefore, the question that is raised at this point is whether the same PDP should be offered to all preservice teachers. Could it be that tailoring a PDP according to preservice teachers initial PDC and PCK for IBL be more effective in training them for understanding and implementing the IBL approach? This remains to be seen in future research since our design did not involve an initial screening of the teachers in terms of their PDC and PCK for IBL. It might be the case that teachers with similar PDC and PCK for IBL perceive the content of a PDP in the same manner, which will enable the PDP instructors to better adapt the PDP to their needs (e.g., have focused discussions which are beneficial to all attendees of the PDP).

Third, the IBL curriculum characteristics that emerged provided in-depth insights about teachers' curriculum design orientations, instructional knowledge and curricular knowledge for IBL, knowledge about students' competence for engaging in inquiry and how to assess their IBL competence, which in turn enabled us to understand aspects of teachers' PCK for IBL. It has been claimed that teachers' PCK for IBL can be developed and enhanced through research-based activities, such as action research and lesson study, employment of classroom practice, use of computer-supported tools, and collaborative learning (Juang et al., 2008). In our study, a considerable emphasis was placed on supporting teachers to develop through a specially designed PDP the necessary PCK for IBL. Following the recommendations of Blanchard et al. (2009), which state that teachers develop their PCK for IBL through applying a model of inquiry they engaged with (probably as learners) to their own lesson designs and implementations, in conjunction with the stance of Kielborn and Gilmer (1999) that teachers' active participation in inquiry science experiences helps them to develop more robust conceptualizations of inquiry and how to teach it to their own students, as well as Irakleous (2015) argument about having the teachers to experience IBL through different angles/perspectives (e.g., teacher as a learner, thinker, curriculum designer, and reflective practitioner), we developed a PDP with four consecutive phases. Each phase was assigned to a different role, to maximize their learning, reflective, and teaching opportunities about IBL. Engaging teachers as curriculum designers, along with other participatory roles (e.g., teachers as learners, thinkers, and reflective practitioners) within the context of a PDP, can create a significant shift in their philosophy and their PDC of how they approach and implement the national curriculum within their practice. This argument concurs with others scholars' recommendations (e.g., Forbes and Davis, 2010) who underlined the importance of engaging preservice teachers to learn to use or revise science curriculum materials to promote IBL. This is because novice teachers tend to rely heavily on the available curricular resources they have access to Grossman and Thompson, 2004, which quite often integrate IBL in a superficial manner (Beyer et al., 2009; Kesidou and Roseman, 2002).

Fourth, the description of the characteristics of teachers' IBL curriculum materials across the levels that emerged enabled us to draw essential inferences about their understandings of the design principles that are important to be followed during developing IBL curriculum materials, their PDC for IBL (Brown, 2009), the types of knowledge transformations applied in the development of these teaching materials, as well as their alternative ideas about how IBL is fostered and assessed within specially designed instructional settings. Expanding on other studies that have identified limitations in preservice and new teachers' PCK for IBL (e.g., Beyer and Davis, 2009; van Driel et al., 1998; Zembal-Saul et al., 2002), the findings of the present study revealed previously identified or new alternative ideas that novice teachers possess while applying their knowledge of science assessment, science curriculum materials, and science instructional strategies.

For instance, in terms of the degree and type of reconstruction of the national curriculum materials, about one-fourth of the pairs of teachers (6 out of 22) let intact the activity sequence of the national curriculum materials. One explanation to account for this decision, which concurs with other reports, is that novice teachers might have assumed that there is no need to revise or reconstruct existing curriculum materials either because it has been developed by experts in the field (Ben-Peretz, 1990; Schwarz et al., 2008) or because they have been published, they are of high quality (Ball and Feiman-Nemser, 1988; Ben-Peretz, 1990).

In addition, teachers' tendency to focus on assessing students' conceptual understanding and neglecting their inquiry competence concerns a finding that was also found in previous research (e.g., Beyer and Davis, 2009). Teachers' preference to design assessment tasks to capture their students' conceptual understanding status might be attributed to either their traditional views of what the purpose of assessment should be (e.g., priority to factual and not to procedural knowledge) (NRC, 1996), or to the limited knowledge about their students' learning needs, or both. Consequently, Beyer and Davis's (2009) claim that preservice teachers tend to engage "…in more thoughtful planning about what they would teach rather than about what they wanted their students to learn and how they would measure it" (p. 151) can be used to explain this finding.

Moreover, the PCK for IBL dimensions through which teachers' characteristics of curriculum designs were elicited from, in conjunction with the description of the emerged levels for every dimension (Table 2 for more details) can be approached as a framework that provides the basis for examining teacher designed and developed curriculum materials from different perspectives, while at the same time inferences about the status of their PDC and PCK for IBL can be extracted. The findings of the present study point to three different profiles of teachers in regard to their PCK for IBL, each of which indicates that the teachers who engaged in the same PDP have conceptualized in diverse ways the underlying principles of the IBL approach as this was reflected through their PDC and PCK. Similar profiles have been elicited in a study conducted by Kazempour and Amirshokoohi (2014), which focused on exploring the impact of science teachers' professional development experiences into their practice. For instance, profile A in their study, which refers to the case of teachers whose emphasis was on the coverage of terminology of background information, resembles profile A of the present study in terms of their curriculum orientations, designed activities, and assessment of students' learning gains. Similarly, profile C (e.g., teachers who are in favor of a more guided inquiry approach) and profile D (e.g., teachers who design more open and student-driven activities) of the Kazempour and Amirshokoohi (2014) study resemble profile B and profile C of the present study, respectively.

In summary, the findings of the present study provide insight into the extent to which preservice elementary teachers develop their PDC and PCK for IBL, as a result of their participation in a specially designed PDP, and apply them for the purposes of curriculum design, adaptation, and implementation. In addition, examining teachers' planning and enactment practices through the use of a five dimension framework, like the one emerged and used in this study, may shed light on the strengths, struggles, and constraints they encounter during applying particular aspects of their PCK into their curriculum designs. Of course, further research, with wider samples and longer exposure to a PDP, is needed before reaching to general conclusions. Another limitation of this study was the fact that we could not study or measure the effect of each of the roles undertaken by the teachers during the PDP (i.e., learners, thinkers, designers, and reflective practitioners) on their PDC and PCK for IBL. To do so, a different research design should be in place. Thus, we encourage future researchers to examine this issue, since understanding the effect of each role would enable us to optimize the effectiveness of the way such a PDP is delivered to the teachers. Finally, a longitudinal study, in which teachers are followed from their preservice years to their in-service ones, is needed to examine how a teacher's PDC and PCK for IBL are evolved. The idea is to collect as much information and evidence as possible for developing a framework that portrays how effective PDPs for IBL should be developed. The ultimate goal is to improve teachers preparation for enacting IBL effectively within their science classrooms.

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ORIGINAL ARTICLE

Making Sense of Responsible Research and Innovation in Science Education through Inquiry-based Learning. Examples from the Field

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ABSTRACT

Originally introduced in several policy documents issued by different institutions belonging to the European Union (EU), 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 paper 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-based learning, which already stresses the importance of active participation as well as students' responsibility for discovering knowledge. To see this potential connection in practice, we conducted an ethnographic study involving seven Estonian science teachers, who agreed to be observed at least 3 times when they conducted inquiry-based 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-based 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 the students are given the opportunity to make meaningful decisions in the different inquiry phases and thus be able to take responsibility for the inquiry process.

KEY WORDS: inquiry-based learning; responsible research and innovation; responsibility as meaningful engagement

INTRODUCTION

Originally introduced in several policy documents issued by different institutions belonging to the European Union (EU), the term responsible research and innovation (hereafter RRI) has gained considerable attention in the recent years among researchers. RRI constitutes an attempt to articulate a theoretical framework that would inform the governance of science in Europe ([reference concealed]). While there are several definitions stressing different aspects, after a review of the literature Burget et al. reached the conclusion that RRI is an "attempt to include all the stakeholders and the public in the early stages of research and development." Including different actors and the public is then viewed to "increase the possibilities to anticipate and discern how research and innovation can or may benefit society as well as prevent any negative consequence from happening" (p. 15). More analytically, it focuses on six aspects or conceptual dimensions (Burget et al., 2017): (a) Collective stewardship of science and innovation (Stilgoe et al., 2013), (b) participation and inclusion of all different actors and stakeholders in the relevant decision-making processes (Bremer et al., 2015; Forsberg et al., 2015), (c) being responsive to problems but also opportunities provided by research as they arise, instead of solely focusing on avoiding negative outcomes (von Schomberg, 2013), (d) a reflective stance addressing specific predicaments related to innovation, such as our finitude and uncertainty (Grinbaum and Groves, 2013), as well as broader ethical issues (Stahl, 2014), (e) a commitment to sustainability, which is defined as the creation and preservation of the conditions under which humans and nature can exist in harmony and which allow fulfilling the social, economic, and other demands for present and future generations (Brundtland, 1987), and (f) care, as a particular form or engagement in and with the world (Adam and Groves, 2011; Bardone and Lind, 2017).

In education - and more specifically in science education, RRI is still very much anchored to the formulations provided in policy documents. De Vocht et al. (2017) acknowledge that "the challenge is to present RRI as a relatable and a meaningful concept rather than an EU policy" (p. 327). As far as we are concerned in this paper, the challenge is two-fold. On the one hand, we need to explore the conceptual and theoretical premises that would make RRI meaningful in the context of science education. On the other, such sense-making process should be grounded empirically onto the educational practice - specifically the practice of science education.

From the theoretical point of view, the highly interdisciplinary framework behind RRI already resonates with a number of well-established strands in science education that could provide – at least in theory - several anchor points, such the Nature of Science (Lederman, 2007), socio-scientific issues (SSI) and socio-scientific inquiry-based learning (SSIBL) (e.g., Sadler, 2011; Kiki-Papadakis and Chaimala, 2016), informal learning in the science, technology, engineering, and mathematics STEM (e.g., Bell et al., 2009). However, in this paper, we pursue another strategy.

In the light of the definition provided above, we may argue that 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, not as a mere "ethical add-on" devoted to discussing the ethical implications of scientific inquiry, but as a term that deals with science and scientific inquiry themselves. Often mentioned as a catchy word, the term responsibility is fundamentally ambiguous: It may refer to an "outcome-based" conception, often replaced by terms such as "accountability" and "liability" (Lucas, 1996; Laughlin, 1996; Inglis, 2000) or to a more "open-ended" one that is connected with care (e.g., Adam and Groves, 2011; Bardone and Lind, 2017). The disambiguation of the term is – we claim – a fundamental step to make to make sense of RRI in science education.

Such conceptual and theoretical task can be empirically grounded by focusing on the practice of inquiry-based learning in the class: This is where students have the opportunity to have first-hand experience of getting in contact with something that bears some resemblance with what real scientists and researchers do and thus actively participate in producing knowledge (e.g., de Jong and van Joolingen, 1998; Chang and Wang, 2009; Bell et al., 2010; Madhuri et al., 2012; Gutwill and Allen, 2012; and Pedast et al., 2015). While the similarities with what researchers and scientists actually do (or are supposed to do) are merely analogical and sometimes a controversial matter (e.g., Hodson, 1998; Hodson and Wong, 2014), an inquiry is characterized by a number of phases, namely, orientation, conceptualization, investigation, conclusion, and discussion (Pedaste et al., 2015), during which students 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 students may be or maybe not given responsibility in and for the inquiry and thus the opportunity to "do RRI."

Establishing the connection between the practice of inquiry-learning, on the one hand, and RRI, on the other, allows us to specify our main research question:

What is the meaning that the term responsibility actually acquires during an inquiry-based lesson?

This main research question can be specified further into two:

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

The text is structured as follows. After detailing the general methodological strategy that we have 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. 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. In the conclusions, we will briefly summarize our contribution and point to possible future developments.

METHODS

Participants

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 students. As the present study is exploratory, we thought that trying to covering the all spectrum would help us see variations of the phenomenon under investigation.

Overall, the age of the teachers ranged from 33 to 59 years old (an average of 44 years) and the continuity of service from 9 to 35 years (an average of 19 years). Five female and three male teachers participated in the study. The subjects teachers taught were biology, physics, chemistry, geography, natural science, human studies, and robotics. The students whom the teachers taught were 8–18 years old. Before the study, all teachers had participated in different training courses held from March 2015 to December 2016. Such training courses varied in nature, as they addressed different topics, such as teachers' digital competences and inquiry-based learning. Nonetheless, they all had a section devoted to the introduction of responsible research and innovation as it was presented in policy documents and other materials coming from projects funded by the EU, namely, Ark of Inquiry and RRI Tools. We asked the teachers who participated in the RRI course to voluntarily take part in the research.

Procedure

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 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

Figure 1: Timeline of the study

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. The length of the interviews varied from 20 to 90 min. We translated the selected extracts from the interviews into English and used them for the study.

We held the pre-fieldwork interviews with 14 teachers. 7 teachers agreed to participate from the second phase of the study onward. After the interviews, we asked permission from the teachers to conduct the fieldwork observations in those classes taught by them where inquiry-based learning as a method was used. The function of fieldwork observations (Wolcott, 1995) was to observe the teachers in action. During the fieldwork, we employed ethnographic techniques such as participant observation in the natural teaching and learning settings – teachers' class – and note-taking.

Observations in the class focused specifically on:

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 students were given responsibility in each phase.

In addition to this schema, we also employed visual ethnographic techniques such as taking pictures (Mullen, 2002). That was meant to help us capture the key moments of the lesson just listed and thus retain as much as possible the kind of ethnographic details characterizing those moments. We decided not to record the whole lesson because using one or two cameras would have given a limited access to what the students and teacher were doing during the inquiry process (Reid et al., 2015). Taking pictures, conversely, allowed us to find the right compromise between observation and documentation.

The fieldwork took place from September 2016 to May 2017. The seven teachers who agreed to participate were observed at least 3 times. A total of 23 lessons and 19 inquiries were observed. Our workgroup consisted of four observers; in every lesson two or three observers were present. After each visit the lesson was discussed in a group with the observers and audio-recorded. Recordings later became part of the data analyzed.

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 students should have.

Data Analysis

As noted above, the major challenge of the present study is to provide a theoretical contribution as to the meaning that RRI can have in science education and at the same time to ground it empirically on to the practice of inquiry-based learning. The conceptual framework of abductive analysis, recently introduced by Tavory and Timmermans (2014) provides the suitable methodological framework for describing a type of research characterized by the interplay between theory, on the one hand, and observation in the field, on the other. According to his advocates, it views data analysis as a methodological practice that helps "stimulate theory generation" (ibid, p. 53). This is accomplished by a "recursive movement back and forth between observations and theories" (p. 65). This means that theorization is not confined to a specific moment during the research, e.g., at the beginning or the end. Conversely, it develops along the way stimulating as well as being stimulated by new interesting and/or surprising observations. This meant that after each visit to inquiry-based learning lessons we paid attention to whether it could add something new to what was already known. When we reached the saturation point, that is, noticed that the familiar patterns had emerged, the observation process stopped.

The data analysis concerning the observations in the class was performed in a team composed of four people – all included as authors of this article. One member in the group has worked as a science teacher for 6 years in Estonia and she played the role of a coresearcher (Bergold and Thomas, 2012). The process of analysis started with analyzing the pictures and fieldwork notes after each visit. The discussions were all audio-recorded for later use. The pictures helped to remember the episodes in the class and discuss emerging topics and categories later in the data analysis process. The pictures also allowed us to see the observations in more detail to avoid any misunderstandings.

Reflections on the data occurred during the discussions, and theoretical elements recursively came into play in the process.

During the discussions, the schemas that emerged from the data were brought out and compared and contrasted with the existing conceptual frameworks concerning responsibility. Finally, a particular, attention was paid in the analysis to the two questions that we mentioned above, namely, how teachers included the students in the inquiry phases and what kind of decisions the students were consequently given responsibility for.

As noted above, the pre- and post-fieldwork interviews added more contexts to what we observed. Pre-fieldwork interviews were analyzed recursively throughout the entire duration of the fieldwork. Post-fieldwork interviews were analyzed in the last phase of the study mostly to find support for the reflections and claims emerged during the previous phase of the study.

EXAMPLES FROM THE FIELD

Two Ideal Types: The Scripted Inquiry and the Open Inquiry

As we have mentioned above, what we are chiefly interested in is investigating the meaning that the term responsibility may acquire in inquiry-based lessons. Specifically, this means to see how teachers included the students in the inquiry process and what kind of decisions students were consequently given responsibility for. The inquiries that we have observed in our 23 visits variably sit along a continuum whose ends express two polarities. On the one end, we had what we may call a "scripted approach to" inquiry; on the other, the "unscripted" or "open" one. While this simple categorization is an ideal one, meaning that the two ends are ideal types, we have found in the post-fieldwork interviews that it is reasonable to accept such categorization.

By "scripted approach" we mean that the teacher furnishes step-by-step guidance in each inquiry phase, steering the process toward the desired goal. Some of the teachers clearly expressed in words a view of inquiry learning in which the teacher actually guides the process, which holds an instrumental value in arriving at the right answer or result. Consequently, they place more emphasis on the preparation of a good plan that would walk the students through the whole process. In the post-fieldwork interview, one teacher explicitly told us that she cannot let students decide because in the end "students solve my problems, not their own." In the same interview, she clarified her stance, adding that what her middle school students would like to do does not fit in the curriculum and the curriculum is what she is supposed to deal with.

By "unscripted" or "open" inquiry, we mean that students 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 students take responsibility for and full ownership of what to do. One of the teachers in the post-fieldwork interview clarified the kind of "openness" that may come to characterize the inquiry process: "I'm like enjoying what's actually going on in the lesson...the intuition, instantly taking advantage of the actual situation [...] you just go with the students and start doing it and this is where the result actually happens."

As we mentioned above, the present study is motivated by a strong commitment to retaining the kind of ethnographic richness that characterizes the practice of inquiry in class. Hence, in presenting the results of our observations, we are going to prioritize the description of some of the cases observed. This is the reason why we decided to present for each inquiry phase three examples, which will hopefully show the variations and differences that have occurred in the different inquiry phases we have observed and prepare the ground for the next section, where we will address the question about responsibility on a theoretical level." See Appendix 1 for an overview.

Before we proceed, it is important to mention that the inquiries observed did not substantially deviate from the inquiry model presented by Pedaste et al. (2015). Specifically, we have identified 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 et al., 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, to avoid being redundant, we decided to leave this phase out and concentrate on the remaining ones.

Another important issue that we would like to clarify concerns the wide range of pupils that we considered, which goes from age 8 to 18. While we expected the age to determine or affect the teaching style and consequently the possibility to give students more or less responsibility, we must say that this was not the case, as far as our sample is concerned. Indeed, there were differences concerning the content. However, we cannot argue that giving responsibility was somehow affected by the age of the students.

A final note: To guarantee the privacy of the teachers involved in the study, the names that are going to appear are pseudonyms.

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 9^{th} graders in collaboration with two biology teachers, Laila and Urmas, 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 student had a tablet at their disposal, the orientation phase ended with the teachers asking the students to download the template from the repository for use during the inquiry. The template contained all the prescribed inquiry phases the students 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 2nd grade students. 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, and next to the radiators. 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 through a discussion, which left room for students to have their own say. Specifically, as the teacher had previously asked the students to bring their own thermometer, she engaged the students in a discussion concerning what kind of thermometer the students had to use to measure the temperature in different places. While it was her leading the way, the students 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 students 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 students, she invited them all to give their own opinion, which the students then tried to explicate. Regarding this specific example, in the post-fieldwork interview teacher Liina told us that she often asks students 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 students 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-min lessons or meetings on 3 consecutive days. Second, as the lessons were part of an elective course that could be freely chosen by gymnasium students.

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 students and, overall, it lasted roughly 15 min.

During the presentation, the teacher showed the students 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 students, 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 students about the plan for the next 2 days. The students had to work in groups to design and conduct an experiment for the 2nd day and present the results to the class on the third. He explicitly stated that students 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 students 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 students. What concerns time management, students were allowed to work outside of the class and, more in general, to manage time their own way. In some cases, students 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.

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. Hence, after the topic was introduced by showing students a clip describing the main components of the heart, the teachers briefly described what they held in stock and then asked the students to guess their heart rate at rest and right after having a run through the entire school building. Students were supposed

	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

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. Students 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 students in the process. Here again the post-fieldwork interview helps provide context. Teacher Urmas expressed his concern in relation to the fact that eventually, students should provide the kind of answer that he expects. He also added that if every student 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 7th grade students. 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 students 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 students, in the conceptualization phase she involved the students directly in formulating the research question. While she herself told the students 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 students 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 students 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 students 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 students 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, students 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 students were aware of how the three lessons were organized, the teacher did not pace them up in any way. The students 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, students worked on the inquiry across 3 consecutive days. Since we only observed the students 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.

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 subphases: 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 7th grade students 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 subphase, the teacher went through the instructions provided in the worksheet that all students received at the beginning of the lesson. The teacher showed, one by one, every single piece of the equipment that the students 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 students would get water. In addition to that she gave the students a practical demonstration as to how to measure the diameter of the cylinder. She took extra care that students would write down the correct units next to the numbers.

Experimentation

During the actual experimentation students 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

	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

of the cylinder and pouring water into the bowl. While the teacher provided a demonstration of measuring the diameter, students had to skilfully put to use a ruler and set square. To fill the bowl with water, students – 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 labor, e.g., who would pour water and who would measure its level in the bowl. The teacher left students freedom to decide whether to work in a group or not, and the students also decided how to assort themselves in the group. Only one student opted for carrying out the task alone.

Compilation and sharing of the results

After the experimentation subphase, the students 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 2nd 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 subphases that we mentioned before.

Design of the experiment

The teacher asked the students to make key decisions along the process. First, she asked the students to bring from home items to bury in the ground. She also assisted them in what followed. After the students 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 center of a small village – had a big garden that extended for a few hundred meters from the school building. Hence, the location for the hole was not entirely obvious. A discussion about the possible location followed. Students 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. Hence, 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 on. Indeed, if the students 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 students 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, students were not given instructions as to how to dig the hole. Conversely, the teacher involved the students in taking active part in what we may call "micro-inquiries," which consisted in deciding on 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 students 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 students 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 subphase drew to an end, the teacher told the students 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 students 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 students. As mentioned above, this was an elective biology course that 10th, 11th, and 12th grade students were free to choose. In this case, too, the investigation phase was characterized by three moments or subphases.

Design of the experiment

Students 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 subphase, the students 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. Hence, 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 students 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 and nose 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 subphase that students had already decided how to divide all the tasks. For example, one group asked students to guess how many grapes a little jar contained. 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 student. 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 students 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 were 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 students did and showed. Figure 4 illustrates the variations occurred in the three cases presented and recapitulates the main differences.

	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 7th grade students. The orientation and conceptualization phases were part of a homework in which students were asked to design an experimental situation where CO_2 would form as a result of a chemical reaction. In the 45-min class the task was to perform, in groups, the experiment that students 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, students were supposed to simply write down the result of the demonstration and were not asked to analyze 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 students knew that CO_2 had formed. Interestingly, in those cases in which the students 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 students 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 2nd grade students 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 students 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 students actively participated in formulating a possible explanation. For example, an explanation that the students 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 student'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 students 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 students 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 students 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 students 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 students had been involved in during the previous 2 days. He took care of naming and describing the elements so that the students 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 students' presentations, the crucial importance of sampling and the way in which results can be visually presented. The students 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.

DISCUSSION: TOWARD MAKING SENSE OF DOING RRI IN SCIENCE EDUCATION

In the introduction, we have maintained that RRI can be fruitfully connected to inquiry-based learning, as this is a

	Example 1	Example 2	Example 3
How conclusions were reached	By writing down the results of the demonstration	Triggered by teacher's questions	None

scripted ⟶ open

Figure 5: Variations during the conceptualization phase

pedagogical framework that at least in theory encourages students to become active in the learning process as well as knowledge creators. Inquiry-based learning can create opportunities for students to become responsible for making decisions throughout all phases of the inquiry process. The examples that we have presented help us better understand what this means or may mean. In this section, we attempt to engage the reader in a discussion on a higher level of abstraction and in so doing specify the meaning that responsibility may have in the present context as well as what we termed "to do RRI."

What we have seen in the previous section is that teachers have adopted a "pattern of inclusion" during the inquiry process. By that we refer to the way in which a teacher comes to involve the students in the different inquiry phases as well as in the inquiry as a whole. The particular pattern of inclusion can be derived from the decisions that students were given responsibility for. Besides, and this is a crucial point, the pattern of inclusion describes a particular interpretation or meaning that can be given to the term "responsibility" and that can consequently help us specify what "doing RRI" may mean.

As mentioned earlier, the notion of responsibility is somehow characterized by a certain degree of conceptual ambiguity (e.g., Adam and Groves, 2011; Laughlin, 1996; Inglis, 2000). Apart from the specific legal meaning that it may acquire, for which the term "liability" is often used, responsibility may designate the situation of being responsible to somebody (Lucas, 1996). This is the meaning that is often present in the everyday use of the word and that we may refer to as "answerability." Lucas (1996) specifies that if I am responsible to someone, "he is entitled to ask me why I did what I did, and I am obliged to answer him" (p. 184). In other contexts (e.g., in the public sector), the word "accountability" is used to denote that the person responsible should give an "account" of what has been done (Giri, 2000).

In more analytical terms, this interpretation of "responsibility" refers to a triadic relation that implies the designation of a person who is held responsible to a third party for accomplishing a task and thus bringing about a certain outcome. Interestingly, the nature of this triadic relation means that, first of all, the person who is held responsible should be able to perform the task assigned. Second, he or she is acting on behalf of another one, his or her superior. Third, as Lucas (1996) has noted, responsibility is shared upward. This means that the superior himself becomes responsible for what the other person – his subordinate – does, as long as he can intervene and correct what the other person is doing.

Interestingly, this is fundamentally the kind of interpretation of responsibility that we have seen in those inquiry phases that were closer to one of the two extremes – the "scripted" type. The presence of a "script" establishes the triadic relation: Students are responsible for the inquiry process in the sense that they are supposed to execute what the teacher has in mind. In turn, the teacher provides the students with the support needed to help them do that. Hence, what we termed "answerability" designates a particular type of inclusion in which the teacher is fully in charge of the inquiry process, whereas the students tend to fall into the role of executors.

If we look at the different inquiry phases, in the orientation phase this meant that students 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, students solve her problem not their own.

We have seen a similar pattern in the conceptualization phase, where the students 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 students should provide the kind of answer he expects.

The investigation phase very much overlaps with the experimentation, and that is the only moment in which – even in the highly scripted type of inquiry – the students 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 students have shown more initiative in conducting the actual experiment, the teacher does not necessarily fade into the background but checks that students are progressing and often paces them up. Besides, the kind of activity the students 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 students have achieved what she/he already had in mind.

What we may claim is that when a pattern of inclusion based on what we called "answerability" is adopted, the chance of doing RRI is somehow de-potentiated, precisely because students are included as executors – they are responsible for simply executing the teacher's instructions. This becomes problematic, because in doing so students may fail to establish a deeper contact with the complexity and uncertainty of the inquiry process and thus – we add – with doing RRI. 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 et al. (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."

Interestingly, in the light of what we have presented in the previous section, the departure from a scripted type of approach established (or contributed to establishing) a different pattern of inclusion and consequently a shift toward a different form of responsibility, which is central for making sense of how doing RRI can be interpreted. As we have shown, in less scripted inquiries the pattern of inclusion adopted by the teacher also changes the kind of decisions students are supposed to make and indeed the meaningfulness of their engagement as well. We see the progressive expansion of what we may call "the space of responsibility" for the students and consequently the possibility of doing 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.

Now, as the space of responsibility expands, students 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 (Pandza and Ellwood, 2013).

As we have seen in less scripted inquiries, in the orientation phase students 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 students 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 students to decide. For example, we have seen that when teacher Liina let her 2nd grade students decide where to dig the hole to bury the items they chose, not only did the students 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 students could give without expecting the "right answer."

What is worth noting here is that the kind of responsibility that the students were given is of a different kind. While it would clearly be an overstatement to say that they ceased to be responsible to the teacher, the students 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 and thus develop what Reed (1996) called primary experience. This – we claim – gives a different meaning to "doing RRI," as being responsible comes to denote more a type of engagement, which is potentially more meaningful precisely because the relationship with the inquiry is less mediated or less "processed" (Reed, 1996). Hence, we may argue that what we called "doing RRI" may come to designate a meaningful engagement with and in the inquiry, which, enabled by the teacher, allows the students 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 process of taking ownership, in which the space of responsibility expands for students, the teacher may come to adopt different roles: For example, that of an initiator of a process, a challenger, a discussant or the one who invites students to inquiring.

CONCLUDING REMARKS AND FUTURE DIRECTIONS

RRI has emerged in recent years as theoretical framework informing how the governance of science can be accomplished so that society – in all its constituencies – can actually benefit from it. The challenge that we have faced in our study and presented in this article is how to make sense of RRI in the specific context of science education. We focused specifically on the meaning that the term responsibility may acquire in inquiry-based learning lessons. We did that, more specifically, by looking at how teachers included students in the inquiry process and what kind of decisions they were then given responsibility for.

The conclusion that we can derive is that the disambiguation of the term responsibility is fundamental to make sense of RRI in science education. When the meaning that the term acquires is closer to what we referred to as "answerability," as far as students are concerned, doing RRI is limited to becoming part of the inquiry process as executors, who simply respond to what the teacher expects them to do. Conversely, when the teacher places more emphasis on the inquiry as a more open-ended process including the students in it, the meaning of the term is closer to the idea of "meaningful engagement." This is an important distinction, because we may conclude that RRI in science education or simply "doing RRI" can be seen as the kind of meaningful engagement that is emerging when students are given the opportunity to contribute during the different inquiry phases for themselves. 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.

From the teacher's point of view, though, including students in the inquiry process and thus leaving it open to their contributions means accepting a certain level of uncertainty and unpredictability, which may come in conflict with what the teacher thinks she/he is expected to do. 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 (Qablan et al., 2009). This is something that inevitably takes us to a different type of path worth investigating in the future.

One last observation: In this article, we have focused on teachers and what was going on in the classroom. This was justified by the fact that we expected the teacher to perform an inclusive role. Indeed, we could tell a completely different story if we turned our attention to other more informal types of activities in which inquiry learning is applied. This might be worth investigating as well, as we may reasonably expect different dynamics to emerge. Moreover, we did not involve students but opted for paying more attention to the kind of dynamics that we saw emerging during the inquiry-based lessons. This means that we are not in the position to provide the story from the students' perspective – especially concerning the different experiences that the different patterns of inquiry may have prompted. This again might be considered an interesting venue to pursue in the future.

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APPENDIX 1

Phase	Example 1	Example 2	Example 3
Orientation			
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
Conceptualization			
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
Investigation			
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
Conclusion			
How conclusions were reached	By writing down the results of the demonstration	Triggered by teacher's questions	None

Scripted → Open

ORIGINAL ARTICLE

Teachers' Experiences of an Inquiry Learning Training Course in Finland

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ABSTRACT

This paper reports outcomes of a 2-day inquiry learning training course for in-service teachers (N=102) with a specific focus on teachers' self-efficacy beliefs, perceptions of inquiry learning, and satisfaction with the training course. Teachers' self-efficacy and their perceptions of inquiry learning were measured both at the beginning and at the end of the training course. Satisfaction with the training course was measured only at the end of the training. The study identified three distinct self-efficacy profiles among the participants: Low, moderate, and high. The self-efficacy of teachers belonging to the high and the moderate group remained unchanged throughout the training, while the self-efficacy for student engagement improved in the low-efficacy group. At the beginning of the training course, differences were found between the low and high self-efficacy profiles in terms of teachers' perceptions of resources for inquiry learning and their anxiety toward inquiry learning; however, only the former difference remained based on the post-test results. Interestingly, although there were three clear self-efficacy profiles and these groups also differed in terms of prior experiences with inquiry learning, all teacher groups were both satisfied in general with the training course and with the utility value of the training.

KEY WORDS: inquiry learning; self-efficacy; teacher training; professional development; science teaching

INTRODUCTION

About a decade ago, several reports (e.g., OECD, 2006; Rocard et al., 2007; and Sjøberg and Schreiner, 2010) pointed out a decline in students' interest toward science. It was also highlighted that the development of students' conceptual understanding, critical thinking skills, and their expectations of studying for a career within the field of science are highly related to how science is being taught in schools. Together, these findings have resulted in initiatives that aim to provide students with science activities that are both effective and inspiring. The most recent PISA assessment from 2015 reported promising results in comparison to these previous outcomes (e.g., OECD, 2006; Rocard et al., 2007; Sjøberg and Schreiner, 2010) in terms of students' interest toward science (Gurría, 2016). These outcomes lend support for the European Union's decision to continue funding research and development projects that aim to reform the science and mathematics education across Europe.

Ark of Inquiry and Inquiry Learning

Ark of Inquiry is one of the EU research and development projects that have received funding from the European Union's Seventh Framework Programme. The project aims to support teachers by providing training and resources for implementing inquiry learning in science education. The project also aims to make inquiry learning accessible to all students and educators due to an increasing consensus that science teaching should be based on an inquiry learning approach with a focus on developing understanding about scientific inquiry instead of only focusing on the traditional subject matter (Anderson, 2007; Lederman et al., 2014; Mant et al., 2007; Slavin et al., 2014). More specifically, the project aims to increase students' interest in science by providing ideas and resources for implementing inquiry learning in schools. The project is founded on an idea of creating a "new science classroom" that provides challenging and exciting ways for learning science through authentic scientific learning experiences. An important part of this vision is to train teachers to support students' inquiry activities in a manner that attracts their interest and motivation toward science as a topic and profession. This study defines inquiry learning as a learner-centered pedagogical approach that aims to involve learners in the scientific discovery process by allowing them to act as real scientists and to participate in scientific investigation to construct new knowledge (Anderson, 2007; Keselman, 2003). In other words, inquiry learning is a form of self-directed learning that includes discovering causal relationships by following the steps of scientific inquiry: Formulating hypotheses, making observations, and/or conducting experiments to test the hypothesis (Pedaste et al., 2012).

Challenges in Implementing Inquiry Learning in Classrooms

Even though recent meta-analyses (Furtak et al., 2012; Lazonder and Harmsen, 2016) have provided evidence on the effectiveness of inquiry learning in contrast to a traditional teacher-centered deductive approach, the pedagogical reform of implementing inquiry learning in science education has not proceeded as expected. The development of science teaching in general is, according to Lewthwaite (2006), influenced by several factors simultaneously: Teachers' personal attribute factors (i.e., interest, motivation, teaching efficacy, and professional science knowledge), environmental factors (i.e., limited time and resources and insufficient external support from the school community), and the interaction of these factors. These factors are also in line with the previous studies (e.g., Choi and Ramsey, 2009 and Ramnarain, 2016) that have investigated factors that specifically influence the implementation of inquiry learning. Yoon et al. (2012) studied the implementation process in more detail, and they found that difficulties are often caused by the open nature of inquiry, teachers' uncertainty of the level of guidance needed in the learning process, teachers' insufficient knowledge of the role of hypotheses in scientific inquiry, and teachers' unconfidence about their science content knowledge.

Inspired by the previous research, this study aimed at investigating whether an inquiry learning training course that was designed in the context of the Ark of Inquiry project had an effect on some of the external and personal attribute factors of teachers in the context of implementing inquiry learning in the classroom. The specific focus was to measure (1) teachers' self-efficacy beliefs in terms of instructional strategies, classroom management, and student engagement, (2) teachers' perceptions toward inquiry learning, and (3) their satisfaction with the training course.

Teachers' self-efficacy

This study investigated teachers' self-efficacy beliefs, which are defined as teachers' own beliefs of their abilities to teach to reach desired educational outcomes (Skaalvik and Skaalvik, 2007). Moreover, teacher self-efficacy is seen as "teachers' belief or conviction that they can influence how well students learn, even those who may be considered difficult or unmotivated" (Guskey and Passaro, 1994. p. 628).

The definition of teacher self-efficacy springs from Bandura's (1997) theory of self-efficacy. He defines self-efficacy as an individual's belief of his or her own ability to perform an act at a certain level and in a given context to reach the desired outcomes (Bandura, 1997). According to Bandura (1997), personal efficacy is one of the most central mechanisms which has an influence on human behavior. It is found to be a multidimensional and a context-specific construct (Zimmerman and Cleary, 2006), which has an influence on the self-regulation of motivation and the amount and persistence of the effort used for performing an act (Bandura, 1977). Furthermore, these beliefs are found to have their own unique contribution beyond the capabilities for achieving the desired outcomes (Bandura, 1997).

Based on the previous research, teacher self-efficacy has been found to have an influence on teacher performance (Appleton and Kindt, 2002; Holzberger et al., 2013; Klassen and Tze, 2014; Rice and Roychoudhury, 2003), teachers' attitudes toward implementing new and innovative teaching strategies (Evers et al., 2002; Guskey, 1988), the amount of effort teachers devote for teaching (Tschannen-Moran and Hoy, 2001), and students' academic achievement (Caprara et al., 2006; Klassen and Tze, 2014). On the contrary, in a longitudinal study by Holzberger et al. (2013), an increase of teacher self-efficacy has been found to be a consequence of different educational phenomena, i.e., students' positive experiences of cognitively challenging tasks and teachers' positive experiences of improved classroom management (Holzberger et al., 2013). Furthermore, it has been found to increase as a result of improved students' academic achievement (Caprara et al., 2006), improved student motivation (Collie et al., 2012), and improved student behavior (Collie et al., 2012). Positive experiences of collaboration between teachers (Collie et al., 2012; Shachar and Shmuelevitz, 1997) and teachers' experiences of support (Hoy and Spero, 2005) have also been found to strengthen teachers' self-efficacy beliefs.

This study aimed at investigating the effect of an inquiry learning training course on teachers' self-efficacy beliefs in the context of implementing inquiry learning in the classroom. A recent meta-analysis investigating the relationship between self-efficacy and training transfer suggested that the strength of teachers' self-efficacy beliefs prior and after the training has an influence on how productively the acquired knowledge and skills are implemented after the training. The study also found that the relationship was stronger after the training, highlighting both the possibility of influencing self-efficacy through training and its positive effect on transfer (Gegenfurtner et al., 2013). This suggests that an increase in self-efficacy could be an equally important outcome of teacher training as deepening content knowledge, which has traditionally been the primary focus in teacher training (Ertmer, 2001; Roberts et al., 2001; Tschannen-Moran and Johnson, 2011).

Teachers' perceptions toward inquiry learning

A natural interest of exploring teachers' perceptions of inquiry learning rose from the fact that the topic of the training course was inquiry learning. Furthermore, as the aim of the training course was to influence teachers' teaching practices, further inspiration came from prior research on the positive association between teachers' conceptions of science teaching and the extent to which teachers used inquiry-based teaching methods in their classroom (Lotter et al., 2007). It has been suggested that to influence teachers' teaching practices also their understanding and beliefs need to be influenced (Kazempour, 2009). A case study by Choi and Ramsey (2009) found that teachers' beliefs and attitudes were positively influenced by a training course that focused on increasing their understanding about inquiry learning. In addition, most of the teachers reported that they had implemented an inquiry learning approach in their teaching at least in some degree after the training and that they were willing to plan more inquiry activities in the future. The study concluded that when teachers felt comfortable with inquiry-based teaching methods, they were more likely to use these methods with their students (Choi and Ramsey, 2009).

Previous research suggests that teachers would benefit from training courses that help to alleviate their uncertainty toward implementing inquiry learning in the classroom. In fact, training courses, in concert with good quality materials, may be the most efficient method for mitigating teachers' lack of academic preparation in science (Nowicki et al., 2013). As such, training courses can have an important role in reforming science education (Choi and Ramsey, 2009). As teachers' perceptions on teaching spring from their personal learning experiences, providing meaningful experiences through training for in-service teachers may therefore also affect their self-efficacy in this respect.

Satisfaction with training

This study also focused on exploring teachers' reactions to the training by exploring how satisfied they were with the training course. The aim was to investigate whether the training course was able to provide sufficient tools and support for teachers with different levels of self-efficacy and different perceptions toward inquiry learning and to collect information on how to improve the design and delivery of the training course in the future. Measuring teachers' satisfaction was considered important since this study did not specifically measure the development of teachers' professional science knowledge in terms of how to implement inquiry learning in the classroom. Gathering information on participants' reactions to the training is, according to Guskey (2000), one of the five levels of evaluating the process of professional development.

Ark of Inquiry Training Course

With the above notions in mind, an inquiry learning training course was developed as a part of the Ark of Inquiry project to address the needs of science educators in Europe. The training course aims to enhance teachers' knowledge base with regard to inquiry learning. It provides teachers with experiences in inquiry learning (both from a learner and from a teacher perspective) based on less open and well-designed inquiry learning activities. It also encourages reflecting upon these experiences to take away some of the uncertainties that teachers may have towards inquiry learning and that withhold them from a higher uptake of inquiry learning in their classrooms. Ideally the training course also aims to even affect teachers' general self-efficacy in teaching.

The training course consists of the following three modules:

1. In teachers as learners, module teachers are given an opportunity to experience the same inquiry learning journeys that their pupils are expected to follow.
2. In teachers as thinkers, module teachers reflect on the learning process that they experienced as learners, identify key elements of that experience (e.g., core content and potential difficulties pupils might experience), and based on these experiences, design an inquiry learning lesson.
3. In teachers as reflective practitioners, module teachers reflect on the implementation of the inquiry learning lesson in the classroom.

The localized version of the training course, on which the results of the present study are based on, consisted of the following three sessions.

1. Training day 1: The first session lasted for approximately 4 h, and it covered the above modules 1 and 2.
   a. At the beginning of this session, the teachers were given a general introduction to the Ark of Inquiry project and inquiry learning, after which they conducted a miniature inquiry activity as learners (they had to figure out the underlying mechanism of a "misbehaving" water container based on the output data).
   b. After this, the teachers were given an in-depth explanation of the Ark of Inquiry learning model with the idea that the model would help teachers to identify different aspects and phases of inquiry, and thus enable them to have more control over the implementation of inquiry learning and the monitoring of students' progress. The Ark of Inquiry model is based on a systematic literature review on inquiry learning models and is cyclic in nature (Pedaste et al., 2015). This model consists of five phases, of which some include subphases: Orientation, conceptualization (subphases: Questioning and Hypothesis Generation), investigation (subphases: Exploration or Experimentation, which lead to Data Interpretation), and finally, the conclusion phase. The discussion phase (subphases: Reflection and Communication) is embedded within all of the abovementioned inquiry phases as it is seen as an important feature of all phases of scientific inquiry. The inquiry cycle is an entity in which the phases are flexibly connected, and hence, it can be widely implemented in different learning contexts (Pedaste et al., 2015).
   c. In the next step, the teachers were given hints on how they could evaluate pupils' knowledge and skills regarding inquiry learning and how they could tailor existing inquiry activities according to their needs. For these purposes, the project has developed pedagogical scenarios and evaluation instruments. It is common that learning materials need modifications and additions before they can be used in the classroom. Six pedagogical scenarios have been developed that guide teachers to evaluate, redesign, improve, and adapt inquiry activities in their classrooms. The evaluation system (that includes various evaluation instruments) used throughout the Ark of Inquiry project assesses pupils' progress in inquiry proficiency by measuring their inquiry skills.
   d. In the last part of the first training session, the teachers registered and logged into the Ark of Inquiry platform, after which they were given guidance on how to search for inquiry activities within the platform. The current version of the Ark of Inquiry online platform includes approximately 560 ready-to-use inquiry

learning activities in 13 different languages that are targeted at students from 7 to 18 years of age. The activities have been evaluated and carefully selected based on how well they support practising of scientific inquiry in STEM domains. The activities follow the Ark of Inquiry learning cycle that constitutes a frame for scientific investigation.

e. As a "home assignment," the teachers were asked to search and select one inquiry activity from the platform or to use their own pre-existing materials and modify them if necessary with the help of the six pedagogical scenarios. Teachers were then asked to implement that inquiry activity in the classroom. This setup gave teachers two options to lower potential feelings of uncertainty. The first, using an activity from the platform, ensured that they were using a structured and well-designed inquiry activity, while the second gave them the opportunity to connect new perspectives from the first session with a familiar activity.

2. Implementation of inquiry learning in the classroom: In the second session, the teachers implemented the self-selected or -designed inquiry activity in their classrooms on their own. They had about a month from the 1st training day to implement the activity with their students. Depending on the selected activity, the duration of the second session varied from 2 to 6 h.
3. Training day 2: In the third and final session, which lasted for approximately 3 h, a group of teachers exchanged their ideas and experiences from the implementation of the inquiry activities. More specifically, everyone gave a short (~10 min) presentation of the inquiry learning lesson that they had designed and implemented and reflected on their experiences from it. Each presentation was followed by a group discussion feedback session. The day ended with a general discussion on how these experiences could be used and extended to further innovate the teaching practices of the school.

Research Questions

The main research questions of this study are as follows:

1. What kind of self-efficacy profiles can be identified among teachers attending the inquiry learning training course?
2. Does the inquiry learning training course change teachers' self-efficacy beliefs within different self-efficacy profiles?
3. How do the perceptions of inquiry learning vary between different self-efficacy profiles, and do these change during the training?
4. Does the satisfaction with the inquiry learning training course vary between different self-efficacy profiles?

METHODS

Participants

The participants of the study were 106 in-service teachers from six schools in five Finnish cities who attended the Ark of Inquiry training course. The training course was mandatory to all teachers in five of the participating schools, whereas it was optional for teachers in one of the schools (n=9). The answers of four participants were excluded from the data analysis as their pre- and post-test answers were not distinguishable due to inaccurate dates on questionnaires. The final participant group included 102 teachers, of which 81 were females (79.4%) and 21 males (20.6%). The average age of the participants was 42.0 (standard deviation [SD]=9.25) years, with a range from 23 to 62 years old. Within this sample, 70 teachers worked in primary education, 17 worked in secondary education, 10 worked in both, and 1 teacher worked in both secondary and upper secondary education. Four teachers did not report the level of education at which they were teaching.

Instrumentation

A Finnish translation of the Ohio State Teacher Efficacy Scale (Tschannen-Moran and Hoy, 2001), which in the recent research has been referred to as Teachers' Sense of Efficacy Scale (TSES) (e.g., Daniels et al., 2017; Dixon et al., 2014; and Klassen and Chiu, 2010), was used to measure teachers' self-efficacy beliefs in three areas of teaching. TSES was chosen because it has been widely used in the field of education for assessing factors that influence teachers' self-efficacy (e.g., Çetin, 2017; Fives and Buehl, 2009; and Poulou, 2007). It is available in two versions: A 24-item version and a shorter 12-item version, of which the longer was used in this study. Items were answered on a 9-point scale ranging from 1 (nothing), 3 (very little), 5 (some influence), 7 (quite a bit) to 9 (a great deal). TSES contains three subscales. The first, efficacy for instructional strategies (8 items, pre-test $\alpha=0.82$, post-test $\alpha=0.83$, e.g., to what extent can you use a variety of assessment strategies?), assesses teachers' self-reported abilities to use and vary between different teaching strategies to adjust the lessons according to students' ability levels. The second subscale, efficacy for classroom management (8 items, $\alpha=0.77$, post-test $\alpha=0.79$, e.g., how much can you do to control disruptive behavior in the classroom?), assesses teachers' self-reported abilities to maintain order in the classroom. The third, efficacy for student engagement (8 items, pre-test $\alpha=0.81$, post-test $\alpha=0.75$, e.g., how much can you do to get students to believe they can do well in school work?), assesses teachers' self-reported abilities to support and motivate students.

Teachers' perceptions of inquiry learning were assessed with a 23-item questionnaire that was devised in the context of the Ark of Inquiry project and translated into Finnish to fit the purposes of this study. The items included in the scale asked teachers to rate their perceptions toward inquiry learning on a 4-point scale ranging from "strongly disagree" (1) to "strongly agree" (4). The questionnaire had no a priori subscales. Cronbach's alpha for the full questionnaire was 0.711, which can be considered low with 23 items. The low total alpha together with some items having almost zero correlation with the total indicated that the questionnaire did not measure a single construct. Exploratory factor analysis (maximum likelihood with Oblimin rotation) was conducted to form subscales based on the pre-test. The analysis indicated the presence of six factors, of which the last two factors were discarded because they centered around one question, and therefore, did not form reliable subscales. In addition, one item was excluded because it had only weak loadings on multiple factors. The four remaining factors explained 45% of the variance in the questionnaire. After inspection of the items, the four factors could be labelled in accordance with previous research (van Aalderen-Smeets et al., 2012). Positive attitude toward inquiry learning (7 items, pre-test α=0.79, post-test α=0.78) included statements indicating a general positive stance toward inquiry learning. Anxiety toward inquiry learning (4 items, pre-test α=0.79, post-test α=0.81) included items relating to uncertainty and unconfidence to implement inquiry learning in the classroom. Resources for inquiry learning (4 items, pre-test α=0.74, post-test α=0.65) included statements relating to availability of materials, time, and tools for implementing inquiry learning. These three factors formed reliable subscales without modifications. The last factor, external support for inquiry learning, included statements relating to the external support from colleagues or the curriculum. Here, one item (successful IBL requires students to have extensive content knowledge) was excluded to maintain a moderate reliability of the subscale on the post-test (4 items, pre-test α=0.72, post-test α=0.69). This resulted in a 19-item scale, which was used in later analyses. Examples of items within the subscales and the four excluded items are presented in Appendix 1.

Teachers' satisfaction with the training course was measured with 13 items that asked teachers to rate their satisfaction with the inquiry learning training course on a 4-point scale ranging from "strongly disagree" (1) to "strongly agree" (4). Following the same procedure as for the perceptions of inquiry learning items, two subscales were created that together explained 61.8% of the variance among the items. The first, general satisfaction (8 items, α=0.92), included statements relating to the length, structure, and relevance of the training. The second, utility satisfaction (5 items, α=0.76), included statements relating to tools and concepts for implementing inquiry learning in the classroom. Examples of items within the subscales are presented in Appendix 2.

Self-efficacy and perceptions of inquiry learning instruments were both used at the pre-test (at the beginning of the first session) and at the post-test (at end of the third session). Satisfaction with the training course questionnaire was used only at the post-test.

RESULTS

Teacher Self-efficacy Profiles

To identify teacher self-efficacy profiles, k-means cluster analyses were conducted based on the responses of 79 teachers that responded to the self-efficacy questionnaire at the pre-test[1]. Based on the results, a three-cluster solution was chosen because it (a) gave clusters of meaningful size and (b) allowed a clear interpretation of the profiles (low, moderate, and high self-efficacy). The cluster sizes resembled normal distribution with 23% of the teachers belonging to the low[2], 47% to the moderate, and 30% to the high cluster.

The low self-efficacy profile cluster included 18 teachers. In this profile, the mean of every self-efficacy subscale was the lowest compared to the other self-efficacy profiles, and within the three subscales, the teachers were the most unsure about their abilities in relation to instructional strategies. Within this profile, 16 teachers were females (89%) and 2 were males (11%). Seven teachers (39%) had previous experiences in inquiry learning, 8 teachers (44%) did not, and 3 teachers (17%) did not answer the question.

The moderate self-efficacy profile cluster included 37 teachers making it the largest of the three profiles. This group included teachers with an already rather high sense of efficacy for instructional strategies, classroom management, and student engagement, with the efficacy for classroom management being a bit higher even than the others. There were 27 females (73%) and 10 males (27%) within this profile. Twenty-five teachers (68%) in this profile had previous experiences in inquiry learning, 6 teachers (16%) did not, and 6 teachers (16%) did not answer the question.

The high self-efficacy profile cluster included 24 teachers who reported the highest level of self-efficacy on all three self-efficacy subscales. Within this profile, there were 20 females (83%) and 4 males (17%). Sixteen teachers (67%) in this profile had previous experiences in inquiry learning, 2 teachers (8%) did not, and 6 teachers (25%) did not answer the question.

Descriptive statistics for each self-efficacy factor for each self-efficacy profile are shown in Table 1. One-way ANOVA and Tukey's *post hoc* tests revealed that with the exceptions of efficacy for classroom management between the moderate and the high self-efficacy profile and efficacy for student engagement between the low and moderate self-efficacy profiles, the three clusters differed significantly on all self-efficacy subscales, $p<0.05$.

Changes in Teachers' Self-efficacy

Paired-samples t-tests were conducted to investigate the changes of the self-efficacy scores within the self-efficacy profiles between the pre- and post-test. These tests showed no significant pre-post differences within the moderate and high self-efficacy profiles ($p>0.05$), whereas in the low self-efficacy profile teachers' self-efficacy for student engagement increased significantly during the training. The means, standard deviations, and the t-test results are shown in Table 2.

1 The sample size dropped from 102 to 79 due to the fact that the training course was run with a tight schedule and with the primary emphasis on the training; some teachers simply run out of time and thus could not answer to the questionnaires.

2 Based on scores alone the low self-efficacy could be qualified as moderate, but because it is lower in comparison to the other two clusters, and because teachers should have at least moderate self-efficacy, they are considered low in the context of this study.

Table 1: Self-efficacy subscale scores of the self-efficacy profiles

Profile	n	Mean±SD		
		Student engagement (1–9)	Classroom management (1–9)	Instructional strategies (1–9)
Low self-efficacy	18	5.78±0.57	5.94±0.75	5.49±0.67
Moderate self-efficacy	37	6.31±0.52	6.81±0.47	6.41±0.44
High self-efficacy	24	7.39±0.60	7.46±0.47	7.50±0.45

SD: Standard deviation

Table 2: Pre- and post-test means of the self-efficacy subscales across the profiles

Profile	Mean±SD			t	p
	Variable	Pre-test	Post-test		
Low self-efficacy (n=11)	SE	5.85±0.49	6.27±0.51	2.590	0.027
	CM	6.13±0.51	6.37±0.76	1.737	0.113
	IS	5.50±0.71	5.92±0.65	1.457	0.176
Moderate self-efficacy (n=29)	SE	6.35±0.51	6.55±0.47	1.846	0.076
	CM	6.78±0.47	6.81±0.65	0.205	0.839
	IS	6.39±0.44	6.56±0.58	1.583	0.125
High self-efficacy (n=17)	SE	7.44±0.60	7.27±0.79	−1.552	0.140
	CM	7.40±0.48	7.22±0.61	−1.217	0.241
	IS	7.59±0.40	7.36±0.64	−1.277	0.220

SE: Student engagement, CM: Classroom management, IS: Instructional strategies. The sample of these analyses includes only teachers who responded to all scales on the pre- and post-test (n=57), and as a result, means are not exactly the same as in Table 1. No corrections against type I error were made for paired t-tests. This decision was based on the results of the linear mixed model (LMM) analyses that were run on the data. In particular, the LMM for self-efficacy on student engagement suggests that, by correcting against type I error, we would most likely conduct a violation against type II error; the LMM showed both a significant main effect for test phase, F (1, 61.685)=5.382, p=0.024, suggesting overall significant change from pre-to-post, and a significant interaction effect between the test phase and the self-efficacy profile, F (2, 61.346)=4.836, p=0.011, suggesting that the pre-post change differed between the profiles, as also indicated by the t-tests. For the remaining paired t-tests, there were no significant results, meaning that the corrections would have no effect on the results.

Perceptions of Inquiry Learning

To address the research question related to teachers' perceptions of inquiry learning, these perceptions were first compared on the pre-test, then on the post-test, and eventually from the perspective of change. One-way ANOVA on pre-test scores showed significant differences between the profiles in anxiety toward inquiry learning, resources for inquiry learning, and external support for inquiry learning, F (2,76)=6.352, p=0.027, F (2,76)=3.776, p=0.003, and F (2,76)=3.425, p=0.038, respectively. Tukey's *post hoc* test results revealed that the differences were significant between the low and high self-efficacy profiles in anxiety toward inquiry learning and resources for inquiry learning, p=0.002 and p=0.021, respectively, whereas no significant differences were detected between the conditions in external support for inquiry learning subscale. No other significant differences were detected. Similar analyses on inquiry learning perceptions at the end of the training course (post-test) revealed significant differences between the self-efficacy profiles in resources for inquiry learning, F (2,54)=3.316, p=0.044, again between the low and high self-efficacy profiles, p=0.034. However, the differences in anxiety and external support that were observed in the pre-test disappeared during the training as no differences were found on these factors in the post-test.

Paired sample t-test on inquiry learning perceptions did not reveal significant changes from pre- to post-test within any of the self-efficacy profiles. In the context of this study, it is noteworthy that all profiles scored above 3 on the positive attitude toward inquiry learning subscale, suggesting that the teachers generally felt very positive toward inquiry learning. Similarly, relatively low scores on anxiety toward inquiry learning subscale do not immediately suggest high anxiety levels toward inquiry learning (Table 3). In the resources for inquiry learning subscale, the post-test scores between the profiles varied from 2.16 to 2.76, with the high self-efficacy group estimating the availability of resources significantly higher than the low-efficacy group. The pre- and post-test scores for external support for inquiry learning (group averages ranging from 3.00 to 3.56) indicate that teachers generally receive sufficient external support for implementing inquiry learning. The means, standard deviations, and the results of the t-test are shown in Table 3.

Satisfaction with the Training Course

Both the general satisfaction with the inquiry learning training course (M=3.10; SD=0.58) and the utility satisfaction (M=2.82; SD=0.61) were high. A one-way ANOVA did not show significant differences between the self-efficacy profiles, suggesting that the groups perceived the training equally

Table 3: Pre- and post-test means of perceptions of inquiry learning subscales across the profiles

Profile	Variable	Mean±SD Pre-test	Mean±SD Post-test	t	p
Low self-efficacy (n=11)	POS	3.07±0.62	3.12±0.53	0.491	0.634
	ANX	2.30±0.51	2.14±0.62	−0.939	0.370
	RES	2.00±0.59	2.16±0.59	0.971	0.190
	EXT	3.00±0.45	3.14±0.55	1.406	0.355
Moderate self-efficacy (n=29)	POS	3.07±0.50	3.03±0.53	−0.484	0.632
	ANX	2.00±0.53	1.78±0.56	−1.674	0.105
	RES	2.41±0.57	2.54±0.58	1.166	0.253
	EXT	3.11±0.58	3.32±0.53	1.279	0.212
High self-efficacy (n=17)	POS	3.36±0.36	3.39±0.33	0.339	0.739
	ANX	1.69±0.65	1.76±0.68	0.676	0.509
	RES	2.66±0.81	2.76±0.70	1.022	0.322
	EXT	3.56±0.38	3.56±0.43	0.000	1.000

POS: Positive attitude toward inquiry learning, ANX: Anxiety toward inquiry learning, RES: Resources for inquiry learning, EXT: External support for inquiry learning, SD: Standard deviation

positively, general satisfaction F (2,55)=1.490, p=0.234, and utility satisfaction F (2,55)=0.847, p=0.434. Although the ANOVA did not reveal significant differences between the self-efficacy profiles, it is interesting that it was the moderate group that had the lowest mean on both general and utility satisfaction (Table 4).

Table 4: Satisfaction with the training course

Variable	Mean±SD Low S-E	Mean±SD Moderate S-E	Mean±SD High S-E
GEN	3.12±0.66	2.98±0.66	3.30±0.38
UTI	2.82±0.63	2.73±0.66	2.98±0.52

GEN: General satisfaction, UTI: Utility satisfaction, SD: Standard deviation

CONCLUSION

Although high expectations are directed toward inquiry learning in the context of reforming science education, and even though the teachers are at the center of this reform, there are surprisingly few studies that have investigated teachers' perceptions of inquiry learning and their attitudes and beliefs around this concept. This study has reported outcomes related to teachers' self-efficacy beliefs, perceptions of inquiry learning, and satisfaction with the training course in the context of an inquiry learning training course. The first aim was to identify self-efficacy profiles among the participating teachers, which resulted in three clearly defined and different teacher profiles which were used as a basis in further analyses. The first notable difference in relation to the profiles was that the low self-efficacy profile contained a much larger percentage of teachers that had never used inquiry in their classroom before. This result is in line with prior research on teachers' previous experiences and exposure to inquiry learning and their confidence to implement the method in their classroom (Choi and Ramsey, 2009).

A study by Lumpe et al. (2000) suggests that teachers who doubt their capabilities need training courses that focus on supporting their beliefs on succeeding. Given the specific nature (inquiry learning) and the relatively short duration of the training course, it was not obvious that the course would be able to change the participants' beliefs of their teaching self-efficacy. The fact that teachers' self-efficacy for student engagement improved during the training course within the low self-efficacy group can therefore be considered an encouraging outcome because the same factors that led to this increase may also stimulate these teachers to implement inquiry in their classrooms more often in the future. The result suggests that even relatively short training courses may have the potential to affect teachers' self-efficacy, at least among those teachers that initially have a lower sense of self-efficacy. Given that the training course reported in the present study did not focus on teachers' self-efficacy explicitly, the above outcome lends support to the general idea that training courses could and maybe should pay more explicit attention on supporting teachers in developing their sense of self-efficacy, as it has been suggested also in the literature (Ertmer, 2001; Roberts et al., 2001; Tschannen-Moran and Johnson, 2011). A reason for why the teachers of the present study experienced an increase particularly in their efficacy for student engagement could be that they were able to directly observe students' engagement and enthusiasm while working on an inquiry activity, which then immediately influenced their confidence on the matter. In case of instructional strategies, for instance, the link is perhaps less obvious and may require more explicit processing and reflection of the training experiences. Future studies should explore whether an inquiry learning training course with a longer duration could influence teacher self-efficacy on all three dimensions measured in this study.

Apart from teachers' self-efficacy, this study also investigated teachers' perceptions related to inquiry learning. At the beginning of the training course, differences were found between the low and high self-efficacy profiles in terms of teachers' perceptions of resources for inquiry learning and their anxiety toward inquiry learning. At the end of the training course, the differences between the teacher profiles regarding resources for inquiry learning had remained, but the differences in terms of anxiety toward inquiry learning were no longer significant. Although the change from pre- to post-test was not significant, the trend of decreasing the anxiety of teachers in the low self-efficacy profile suggests that a prolonged training may be able to reduce the anxiety substantially (and significantly). In relation to the view of external resources, an interesting follow-up question would be to see whether these figures are a reflection of the reality (these teachers have less resources, which may partly explain their self-efficacy) or teachers' perceptions (meaning that self-efficacy influences how one perceives resources).

This study also assessed teachers' satisfaction with the training, and one of the interesting outcomes was that even though the training course did not have a significant impact on teachers' perceptions of inquiry learning, and although there were three clearly different profiles of teachers with respect to perceived teaching self-efficacy and these groups also differed in terms of prior inquiry learning experiences, all teacher groups were both satisfied in general with the training course and with the utility value of the training. Even though the differences were not statistically significant, it is interesting that it was the moderate self-efficacy group that reported the lowest satisfaction on both scales. This suggests that though they were not unsatisfied, there might still be something missing for the teachers in this self-efficacy profile that would enhance both their general and utility satisfaction. In the future studies, it might therefore be of interest to find more about the origins of general and utility satisfaction for teachers as this may help the design of a course that can differentiate support for teachers from all self-efficacy profiles.

This study has some limitations that should be addressed in the future research. One limitation is that the results are based solely on self-report data. Although the opinions diverge around the reliability and validity of self-reported data (e.g. Chan, 2009; Cook and Campbell, 1979), it is clear that to obtain a higher reliability, follow-up studies should employ a variety of data gathering methods (e.g., classroom observations and teacher interviews).

Another limitation was that the data were gathered only at the beginning and at the end of the training course, that is, no data were gathered during the actual implementation phase in the classrooms, though the success of the implementation likely has an effect on both teachers' self-efficacy beliefs and perceptions of inquiry learning. In relation to this limitation, more specific studies on the relationship between training, implementation of inquiry learning in classrooms, and teachers' inquiry perceptions are needed because it is surprising that the training had an effect on teachers' self-efficacy beliefs but not on their perceptions of inquiry learning. The questionnaire that was used for measuring teachers' perceptions of inquiry learning would also benefit from further testing, for instance, can other studies replicate the subscales that were derived from EFA and could the scales be extended with new items to obtain higher reliability? In general, since inquiry learning and teachers are envisioned to play a key role in the reform of science education, more and different kinds of interventions, training courses, and studies are needed on this theme. The present study and the training course that was implemented in the context of the study form a foundation for future work.

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Appendix

Appendix 1: Items and reliabilities of the four subscales forming the perceptions of inquiry learning scale

Positive attitude toward inquiry learning (7 items, α [pre-test]=0.79, α [post-test]=0.78)

1. IBL is well suited to overcome problems with students' motivation
2. IBL provides material for fun activities
3. IBL is well suited to approach students learning problems
4. I would like to implement more IBL practices in my lessons
5. I would like to have more support to integrate IBL in my lessons
6. IBL is not effective with lower-achieving students
7. I see no need to use IBL approaches

Anxiety toward inquiry learning (4 items, α [pre-test]=0.79, α [post-test]=0.81)

1. I worry about students' discipline being more difficult in IBL lessons
2. I do not feel confident with IBL
3. I think that group work is difficult to manage
4. The number of students in my classes is too big for IBL to be effective

Resources for inquiry learning (4 items, α [pre-test]=0.74, α [post-test]=0.65)

1. I do not have enough time to prepare IBL lessons
2. I do not have sufficient resources such as computers, laboratory
3. There is not enough time in the curriculum
4. I worry about my students getting lost and frustrated in their learning

External support for inquiry learning (4 items, α [pre-test]=0.72, α [post-test]=0.69)

1. The curriculum does not encourage IBL
2. My colleagues do not support IBL
3. My students have to take assessments that don't reward IBL
4. I do not have access to any adequate professional development programs involving IBL

To help interpretation, the scales resources for inquiry learning and external support for inquiry learning were reversed for the reporting. The items I already use IBL a great deal, and I do not have adequate teaching materials were excluded from the scale because they formed factors that centered around one question. The item I do not know how to assess IBL was excluded because it had only weak loadings on multiple factors. The item Successful IBL requires students to have extensive content knowledge was excluded from the external support for inquiry learning subscale to maintain a moderate reliability of the subscale on the post-test. A Finnish translation of the questionnaire was used in the data collection.

Appendix 2: Items and reliabilities of two subscales forming the satisfaction with the training course scale

General satisfaction with the training (8 items, α=0.92)

1. Training was well organized
2. The lengths of the training days were appropriate
3. The content of the training was essential
4. The content of the training corresponded to my needs
5. The material presented in the training was useful
6. Training has been useful for carrying out inquiry learning in my own teaching
7. I enjoyed the training
8. Training motivated me to carry out inquiry learning with my students

Utility satisfaction (5 items, α=0.76)

1. I have become more familiar with the term "inquiry learning" during the training
2. I have become more familiar with the term "responsible research and innovation" during the training
3. Training helps me to utilize suitable materials for my own and the needs of my students
4. Training helps me to assess the skill levels of inquiry learning
5. Training helps me to develop responsible research and innovation activities in my teaching through a reward system

A Finnish translation of the questionnaire was used in the data collection.

ORIGINAL ARTICLE

Teachers' Readiness to Use Inquiry-based Learning: An Investigation of Teachers' Sense of Efficacy and Attitudes toward Inquiry-based Learning

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ABSTRACT

The use of inquiry-based learning (IBL) is encouraged in schools, as it has been shown to be an effective method for raising students' motivation in STEM subjects and increasing their understanding of scientific concepts. Nevertheless, IBL is not very often used in classrooms by teachers due to different (perceived) obstacles. Within the Ark of Inquiry project, teacher training sessions were designed that enabled the teachers to experience IBL from different perspectives: Teacher as a learner, teacher as a thinker, and teacher as a reflective practitioner. We expected that the trainings would have an impact on teachers' sense of efficacy (TE), which has been shown to be positively related to teachers' readiness to adopt new teaching methods, and their attitudes toward IBL. Four hundred and ninety-seven teachers from 10 countries were involved in the study. We found that teachers' higher sense of efficacy was related to more positive attitudes toward IBL before the training. The teacher training sessions had a positive effect on the Student Engagement Subscale of TE ($d = 0.16$) and attitudes toward IBL. The strongest positive effects on attitudes were related to the perceived available resources for teaching inquiry ($d = 0.36$) and inquiry being suitable for motivating different students ($d = 0.28$). However, the training did not impact how teachers perceive systemic restrictions. The study concludes that this kind of teacher training can be a suitable method of boosting TE and overcoming some perceived obstacles for adopting IBL in the classroom.

KEY WORDS: inquiry-based learning; teacher efficacy; science, technology, engineering and mathematics learning; teacher training; attitudes toward inquiry

INTRODUCTION

Increasing students' interest in science, technology, engineering, and mathematics (STEM) continues to be one of the major educational priorities in many European countries according to a study where 30 countries were asked about their strategies for improving STEM education (Kearney, 2016). Inquiry-based learning (IBL) is a possible solution to address the issue of students' low motivation for learning STEM subjects and is therefore included in several curriculum reforms in European countries (Kearney, 2016; Rocard et al., 2007; Pedaste, 2017; Pedaste et al., 2016; Pedaste and Mäeots, 2012). IBL is a student-centered way of learning where students develop their own questions to examine, engage in self-directed inquiry (diagnosing problems - formulating hypotheses - identifying variables - collecting data - documenting their work - interpreting and communicating results), and collaborate with each other (National Research Council, 2000; de Jong, 2006; Dorier and Maaß, 2012; Pedaste et al., 2015). The aim of IBL is to stimulate students to adopt a critical inquiring mind and problem-solving aptitudes (Dorier and Maaß, 2012). Guided inquiry, in particular, has been shown to be an effective method for learning science compared to unguided inquiry (Minner et al., 2010; Lazonder and Harmsen, 2016). Within guided inquiry, the teacher or learning environment can give various types of support (e.g., prompts, heuristics, and scaffolds) to the student who is involved in inquiry learning (Lazonder and Harmsen, 2016).

Nevertheless, it has been found that teachers do not apply the inquiry approach in their classrooms as much as expected (Capps and Crawford, 2013a). In a study based on Trends in International Mathematics and Science Study 2007, it was indicated that teacher's level of experience is one possible predictor of utilizing inquiry-based methods in the classroom (Kuzhabekova, 2015). In another study (Isiksal-Bostan et al., 2015), it was found that teaching experience is positively related to beliefs in using traditional teaching approaches but not to beliefs in inquiry-based teaching approaches. Furthermore, Xie and Sharif (2014) did not find a significant relationship between implementation of IBL and teachers' years of experience. Therefore, the relationship between teaching experience and readiness to use inquiry-based approach is not completely clear, and it is not clear whether teacher training should address teachers with different levels of experience differently.

Capps and Crawford (2013a) and Colburn (2000) bring out lack of understanding and knowledge of inquiry as a reason for teachers not using IBL, for example, the definition of inquiry is unclear and teachers do not know what is expected from them. In addition, prior research shows that for an effective implementation of IBL, and teachers must have refined pedagogical content knowledge for IBL (i.e., proper knowledge of orientations congruous with inquiry, learning strategies for implementing inquiry, students' perception of inquiry, inquiry-based teaching materials, and techniques for assessing inquiry) (Crawford, 2000; Davis and Krajcik, 2005).

There are also various other barriers that teachers need to overcome before the new approach can be implemented. These go well beyond a specific knowledge of IBL methods. Anderson (2002) divides barriers into three clusters: Technical, political, and cultural. Among others, technical barriers include teachers' prior commitment to textbooks, challenges of assessment, and difficulties with managing group work. Political barriers concern parental resistance, unsolved conflicts between teachers, and lack of resources. Cultural barriers are connected to teachers' beliefs and values and commitment to prepare students for the next level of education. The relevance of teacher beliefs for using new methods in the classroom has been stressed by several researchers (e.g., Bhattacharyya et al., 2009; McKeown et al., 2016). In addition, Fishman et al. (2003) found that one goal of professional development should be to influence these beliefs.

Even though authors have used varying terminology and clusters to describe the barriers, there are significant similarities. For example, the understanding of inquiry would be a technical barrier according to Anderson's (2002) view. In the PRIMAS study (Dorier and Maaß, 2012), an effort was made to make an empirical model of the challenges related to implementing IBL. For that, a questionnaire was developed to capture problems that teachers expect to face when implementing IBL. Based on the literature, 15 items were composed, and factor analysis revealed the following three factors: System restrictions, classroom management, and resources (Table 1). These were also supported by the open question analysis in the PRIMAS study. Thus, this can be used as a basis for new empirical studies. It also illustrates how the barriers are related to more aspects than just not enough knowledge of how to implement IBL. When comparing the factors to Anderson's (2002) model, then system restrictions mostly overlap with cultural and political barriers, classroom management with technical barriers, and resources with political barriers, respectively.

There is continuous effort to overcome these barriers. To unify the understanding about IBL, Pedaste et al. (2015) conducted a literature review to bring together different views on inquiry in STEM context; and based on that, they created a cyclical model of inquiry describing all the steps of inquiry within STEM. Furthermore, systemic restrictions are tackled on a political level by changing science curricula in European countries (Kearney, 2016), for systemic restrictions include teachers' perceptions about the curriculum not encouraging IBL. An effort to establish change in teachers' beliefs is made through educating teachers.

Teachers' Beliefs and Teacher Training

Literature indicates that teachers' higher sense of efficacy is related to their readiness to adopt new teaching methods such as inquiry (e.g., Voet and De Wever, 2017). Tschannen-Moran and Hoy (2001. p. 783) use the term "teacher efficacy" and conclude from the previous literature that teachers with higher teacher efficacy "are more open to new ideas and are more willing to experiment with new methods to better meet the needs of their students." They defined teacher efficacy as "a judgment of his or her capabilities to bring about desired outcomes of student engagement and learning, even among those students who may be difficult or unmotivated" and found relationships between teacher efficacy and student outcomes such as achievement, motivation, and students' sense of efficacy. Therefore, in addition to specific skills and IBL-related beliefs (e.g., belief that IBL is very difficult to manage and suitable only for very knowledgeable students), general teacher efficacy should be considered when promoting change in teachers' behavior.

Teacher training has been suggested as an effective way to increase teachers' motivation and readiness to adopt new approaches such as inquiry into their teaching. Different authors have brought out several aspects to be considered by the teacher educators that would make the teacher trainings most effective. Capps and Crawford (2013b) stress the importance of teachers engaging in authentic scientific investigation, supporting teachers in how to use the inquiry approach, and supporting the reflection of teachers. Based on their study results, Voet and De Wever (2017) argue that to achieve positive effects on students, teachers' attitudes toward the inquiry approach and perceived competence to teach IBL, trainings should focus on (1) stimulating active learning, (2) changing beliefs, and (3) providing a practical guide.

Until recently, there have not been many training programs specifically aimed at the inquiry approach and improving teachers' knowledge and attitudes toward it. Yet, there is already some evidence that positive effects can be achieved through specially designed teacher training courses. For example, Ertikanto et al. (2017) report success with a teacher training program implemented in Indonesia that was designed to follow Bandura's stages of social learning (learning by observing): Attention, retention, production, and motivation. The effect was observed on teachers' inquiry skills. Perez and Furman (2016) found that a 10-month professional development course in Peru, which engaged teachers in designing inquiry-based lessons, had a positive impact on teachers' practice of inquiry. The authors concluded that the factors that counted for the change were teachers' revised views, engaging in inquiry activities themselves and trying out the inquiry approach within their classroom.

Table 1: Subscales of the PRIMAS questionnaire with internal consistency measurements

Area	Subscale	Items/description	Cr. alpha	Mean inter-item correlation	N of Items	N
Use of IBL	Routine use of IBL	I already use IBL a great deal	-	-	1	380
Preconception of IBL	Knowledge dependencew	Successful IBL requires students to have extensive content knowledge	0.521	0.353	2	347
		IBL is not effective with lower-achieving students				
	Motivation	IBL is well suited to overcome problems with students' motivation	0.582	0.411	2	345
		IBL is well suited to approach students' learning problems				
Problems with implementation	Resources	I do not have sufficient resources such as computers and laboratory	0.629	0.359	3	375
		I do not have access to any adequate professional development programs involving IBL				
		I do not have adequate teaching materials				
	Classroom management	I think that group work is difficult to manage	0.692	0.360	4	376
		I worry about students' discipline being more difficult in IBL lessons				
		I do not feel confident with IBL. I worry about my students getting lost and frustrated in their learning				
	Systemic restrictions	My students have to take assessments that do not reward IBL	0.654	0.323	4	347
		The number of students in my classes is too big for IBL to be effective				
		The curriculum does not encourage IBL				
		There is not enough time in the curriculum				

IBL: Inquiry-based learning

Furthermore, in the present study, a specially designed model of teacher training was used. This particular model was the result of a thorough literature review of the domain (for details see Irakleous, 2015 and Papaevripidou et al., 2017). During this process, several aspects, which were found to positively affect teachers' understandings about IBL, were combined together to bring the best of the previous models and frameworks together. The overarching outcome of this review was that for a successful teacher training, the teachers need to experience inquiry from different perspectives to capture the whole picture of what IBL is and how it is effectively enacted. To offer the teachers different perspectives on looking into IBL, researchers suggest having the teachers experience inquiry by undertaking different roles (e.g., teachers as learners, teachers as reflective practitioners). As a result, we developed a teacher training model which includes three phases. Each phase corresponds to a different teacher role, namely, teachers as learners, teachers as thinkers, and teachers as reflective practitioners.

The first phase - teachers as learners - positions the teachers in the role of active learners, letting them experience learning as their students do. For instance, stepping into the students' shoes enables teachers to experience issues and struggles similar to those of their students. Prior research has shown this to be beneficial for teachers' professional development (e.g., Clarke and Hollingsworth, 2002; Kazempour and Amirshokoohi, 2014; Kerlin, 2012).

In the second phase - teachers as thinkers - teachers have the opportunity to develop their understanding and knowledge about inquiry (Akerson et al., 2007), for example, through reading about theory and class discussions. In addition, teachers are encouraged to compare the theoretical framework constructed in this phase with the empirical understanding they have gained while experiencing the teachers as learners phase - this enables teachers to put their knowledge into practice and *vice versa*, which results in a better understanding of IBL.

The third phase - teachers as reflective practitioners - concentrates on reflecting on the experience gained in the previous two phases and materializing it by designing and developing inquiry-based teaching materials, which in turn are enacted in science classes. In addition, the teachers are further prompted to reflect on their inquiry implementations. The idea is to have teachers reflect on their failures and successes. Reflection is also an important part of teachers' professional development (Ferraro, 2010).

Although IBL has been found effective and some steps have been taken to overcome the described barriers, it is still not used in the classroom as much as expected and we are therefore still looking for effective ways to promote inquiry (Pedaste et al., 2016). Furthermore, many of the strategies, policies, and initiatives to improve STEM education are relatively recent, and therefore, it is advised for "the European research and policy-making communities to follow their development and monitor their impact to STEM education progress" (Kearney, 2016. p. 83). Thus, the implementation of IBL in classrooms is still an ongoing endeavor that needs further input from research to identify effective inquiry-based practices and introduce these to teachers (Van Joolingen and Zacharia, 2009).

Aims and Research Questions

Our aim was to find whether our model designed for teacher training would have an effect on teachers' attitudes toward inquiry and their teaching-related sense of efficacy. To address the relationships between teachers' attitudes and the possible effect of the teacher training sessions, we formulated the following three research questions:

1. Is prior use of inquiry and teaching experience related to teachers' attitudes toward inquiry?
   As previous studies have indicated controversial findings about the relationship between teaching experience and readiness to use IBL, we wanted to know whether teaching experience and experience with IBL have a positive effect on attitudes toward IBL or is IBL equally challenging for more experienced teachers.
2. Is teachers' sense of efficacy (TE) related to attitudes toward the inquiry approach?
   Our second research question stands on two assumptions: (1) Attitudes toward IBL predict use of IBL, whereas negative beliefs are seen as barriers to implementing IBL and are therefore relevant mediators; (2) TE is an important prerequisite for teachers' readiness to start using new methods. We assume that teachers' higher sense of efficacy is related to perceiving less barriers for implementing IBL.
3. Do the teacher training sessions have an impact on TE and attitudes toward inquiry and if so in which areas is it more pronounced?
   Essential aspects of effective IBL teacher trainings have been suggested in the literature. We wanted to find whether a teacher training session that considers these aspects has an effect on teachers' attitudes toward IBL, and moreover, on a more general construct of TE.

METHODS

Context

Ark of Inquiry is a research and development project funded by the European Commission (Pedaste et al., 2015; http://arkofinquiry.eu). The project involves 13 partners from 12 countries, who collaboratively aim to promote interest in science through IBL, which is linked to the Responsible Research and Innovation approach (Burget et al., 2016). Within the project, a web platform was created with carefully selected inquiry-based activities, and web-based materials were developed to support guided inquiry. For supporting the teachers, face-to-face trainings were provided to them in all the countries involved in the project, following the aforementioned model of training.

Sample

From all the Ark of Inquiry project partners, 10 countries had the opportunity to collect data about TE and attitudes toward inquiry. The samples are not representative of the countries and the groups are not balanced between countries. 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 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. More information about the participants was summarized in Table 2.

It is evident from Table 2 that the number of participants in the trainings was much larger than the available data. This has several reasons. In many cases, this has to do with the dropout of teachers from the program and failure to fill in the questionnaire at the given time and place (e.g., they left before the end of the session). One reason for dropout stems from teachers' busy schedule, due to which in some cases they were not able to attend the second session. 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.

The distribution of teachers based on their teaching experience can be seen in Table 3. Four teachers did not report their teaching experience.

Instruments

TE scale (Tschannen-Moran and Hoy, 2001) was used to measure TE at the start and at the end of the training. The scale consists of 24 questions designed to capture the three moderately correlated subscales related to being a teacher: Student engagement (e.g., getting students to believe they can do well in schoolwork and helping students value learning), classroom management (e.g., controlling disruptive behavior in the classroom and calming disruptive students), and instructional strategies (e.g., using a variety of assessment tools and 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. In the case of preservice teachers, the 1-factor model has had a better fit for the data (Tschannen-Moran and Hoy, 2001).

Table 2: 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

Table 3: Participants' teaching experience (in years)

Years of teaching experience	0–5	6–15	>16
N	77	184	232
% of total	15.5%	37.0%	46.7%

Four teachers (0.8% did not report their teaching experience)

In our sample, we found that the internal consistency of the different subscales was good or very good (Cronbach's alpha ranging from 0.878 to 0.909). Confirmatory factor analysis was used to confirm the factor structure in the current sample. The factor loadings of the items are high in the three-factor model, but the constructs were strongly correlated (ranging from 0.79 to 0.89). A moderate correlation of the subscales was also noted by the authors of the TE scale, ranging from 0.58 to 0.70 (Tschannen-Moran and Hoy, 2001). Based on our data, we see that the 3-factor model is a better fit to the data than 1-factor model (Table 4), although the fit indices of the model are not as good as expected. We used several fit indices to evaluate the model, namely, Chi-square, the root mean square error of approximation (RMSEA; Browne et al., 1993), the comparative fit index (CFI; Bentler, 1990), and the standardized root mean square residual (SRMR; Jöreskog and Sörbom, 1989). We considered the following cutoff values as indicators of good fit: 0.06 or below for the RMSEA, 0.95 or greater for the CFI, and .08 or below for the SRMR (Brown, 2006; Hu and Bentler, 1999). We see that only SRMR indicates a good fit.

Attitudes toward IBL were measured by one part of a questionnaire that was used in the PRIMAS project (Dorier and Maaß, 2012) to analyze teachers' use and preconception of inquiry and their problems with the implementation of IBL. 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 with the given statements (Table 1 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 IBL (internal consistency measurements were given with Cronbach's alphas varying from 0.54 to 0.60).

Table 4: 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; <0.001)	1022.014 (249; <0.001)
RMSEA	0.105	0.090
CFI	0.805	0.858
SRMR	0.068	0.061

CFI: Comparative fit index, RMSEA: Root mean square error of approximation, SRMR: standardized root mean square residual

A three-factor structure was found in the PRIMAS project for the subscales about problems with implementing IBL: System restrictions, classroom management, and resources (Table 1). Confirmatory factor analysis was used to confirm the factor structure in the current sample, and the fit was relatively good ($\chi^2(41)=102.6$, $p<0.001$; RMSEA=0.063; CFI=0.928; TLI=0.903; SRMR = 0.049). The factors' correlations with each other varied from 0.49 to 0.84. The internal consistency measurements for the IBL 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 0.2 to 0.4. In our sample, the mean inter-item correlations vary between 0.323 and 0.411. Subscales with Cronbach's alphas lower than 0.5 were not used in the study and statistical analysis.

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

Procedure

The principles of 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 (see http://www.

arkofinquiry.eu/web-based-materials). The teacher training consisted of three phases (teacher as a learner, teacher as a thinker, and teacher as a reflective practitioner). Phases 1 and 2 were tackled in 1 or 2 days of teacher training depending on whether the teachers had previously hands-on experiences with IBL or not. At the beginning of the first training day, teachers filled in the questionnaire about TE and their attitudes toward IBL. After the second phase, the teachers had a few months to practice IBL 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 2 or 3 days including several months of practice time.

Within the training, the teachers had an opportunity to experience inquiry from the learner's viewpoint. Furthermore, different resources for conducting inquiry were introduced, including the Ark of Inquiry web-based platform with a collection of different inquiry activities that the 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 filled in online or on paper, depending on whether computers were available for use or not.

An average overall TE score and averages for the three subscales were calculated from the questionnaire data. Average scores were also calculated for the attitudes toward inquiry subscales as suggested by the original authors.

Q-Q plots were used to visually determine whether the distributions of data were approximately normal, and this was found to be the case for the TE scores and IBL subscales. T-tests and one-way ANOVA with Levene's test for equal variance were used for group mean comparisons. In cases where the assumption of equal variances was violated, Welch's t-test was used to determine the statistical difference. In case of very different group sizes (1.5-fold difference), nonparametric tests were preferred. A $p<0.05$ was considered statistically significant for all tests. In cases of multiple comparisons, we used the Holm-Bonferroni Sequential Correction (Gaetano, 2013). The corrected p values are marked with p'. Cases with missing data were excluded analysis by analysis. The data were analyzed with SPSS 20 and Mplus 7.4 software.

RESULTS

The Relationship between Prior Teaching Experience and Teacher Attitudes

The average score for TE before the training was 6.69, and values are ranging from 2.96 to 9.0 (Table 5 for more details). Kruskal-Wallis one-way ANOVA revealed that TE before the teacher training sessions was not related to the years of teaching experience: Comparing teachers with 0–5 (n=77); 6–15 (n=184), and 16 or more years of teaching experience (n=232) revealed no significant differences, $\chi^2(2)=3.891$, $p=0.143$.

Attitudes toward IBL were measured on a scale from 1 to 4 with mean scores, sample size, and SD provided in Table 5. Attitudes toward IBL were similar for teachers with varying levels of experience ($p>0.05$).

The Relationship between Prior Use of Inquiry and Teachers' Attitudes toward Inquiry

Two groups were created based on prior use of IBL (agreement with the statement "I already use IBL a great deal" ranging from 1 to 4). This was used as an indicator for the prior use of IBL and answers 1 ("strongly disagree") and 2 ("disagree") were pooled together into a group labelled "no or very little use;" answers 3 ("agree") and 4 ("strongly agree") were pooled together to form a group "somewhat or high use." This resulted in approximately equally sized groups. Independent samples t-test was used to test for differences in the 5 factors among two groups of teachers. We used Holm-Bonferroni correction to control for Type 1 error and present p' which is the adjusted p value. The test revealed that teachers who already use IBL and those who use it very rarely exhibit significant differences in preconceptions about IBL. These differences are significant for knowledge dependence, $t(343)=3.212$, $p'=0.005$, and classroom management, $t(375)=2.729$, $p'=0.028$, but not for resources, $t(376)=2.089$, $p'=0.074$. The assumption of homogeneity of variance was violated for the motivation subscale; therefore, the Welch-Satterthwaite method was used to adjust degrees of freedom, and a significant difference was found, $t(334)=-2.536$, $p'=0.036$. However, the prior use of IBL is not related to systemic restrictions, $t(376)=1.505$, $p'=0.133$. We have also presented Cohen's *d* that shows the effect size in units of standard deviation (Table 6).

The Relationship between Teachers' Sense of Efficacy and Attitudes toward the Inquiry Approach

The TE score was used to create two groups: Teachers with high (M=7.4) and low TE (M=6.0) (Table 7). These groups were created based on the median score of 6.75. The independent samples T-test revealed that teachers with an overall higher level of TE are more positive toward inquiry and report lower levels of different types of potential restrictions, such as difficulties with classroom management, $t(379)=7.086$, $p'<0.001$; systemic, $t(380)=3.848$, $p'<0.001$ and resource restrictions, $t(380)=3.092$, $p'=0.006$. Furthermore, they see inquiry as a motivation-enhancing tool for students, $t(347)=-2.613$, $p'=0.006$, and not as highly knowledge dependent, $t(347)=3.038$, $p'=0.009$.

Effects of Training on TE

Pre- and post-training data are available for 228 teachers. The mean TE score for these teachers was 6.69 before the training and 6.82 after the training. The effect of training was not evident on the overall score of TE, as revealed by the paired samples t-test, $t(227)=-2.291$, $p'=0.069$, though the effect is notable in the student engagement subscale, $t(227)=-2.290$, $p'=0.016$; no significant difference was found between pre- and post-test measurements of the classroom management [$t(227)=-1.399$, $p'=0.163$] and instructional strategies

Table 5: Pre-training means and standard deviations of the teachers' sense of efficacy and attitudes toward IBL in the sample

Scale	M (scale from 1 to 9)	Range	N	SD
1. Teacher efficacy	6.7	2.96–9.00	382	1.00
1.1 Student engagement	6.6	2.38–9.00	382	1.15
1.2 Classroom management	6.8	2.00–9.00	382	1.11
1.3 Instructional strategies	6.7	3.38–9.00	382	1.02
Scale	**M (scale from 1 to 4)**	**Range**	**N**	**SD**
2. Attitudes toward IBL				
2.1 Knowledge dependence	2.3	1.00–4.00	349	0.71
2.2 Motivation	3.0	1.00–4.00	349	0.61
2.3 Resources	2.5	1.00–4.00	382	0.64
2.4 Classroom management	2.1	1.00–3.75	381	0.57
2.5 Systemic restrictions	2.5	1.00–4.00	382	0.65

IBL: Inquiry-based learning, SD: Standard deviation

Table 6: Attitudes toward IBL among teachers who have used IBL in the classroom and those who have not or have used it very little

Subscale/frequency of use	N	M (scale from 1 to 4)	SD	SE	Cohen's *d*
Knowledge dependence*					
No or very little use	165	2.4	0.69	0.05	0.35
Somewhat or high use	180	2.1	0.73	0.05	
Motivation*					
No or very little use	165	2.9	0.63	0.05	−0.27
Somewhat or high use	180	3.0	0.58	0.04	
Resources					
No or very little use	189	2.6	0.62	0.05	-
Somewhat or high use	189	2.5	0.66	0.05	
Classroom management*					
No or very little use	188	2.2	0.60	0.04	0.28
Somewhat or high use	189	2.0	0.53	0.04	
Systemic restrictions					
No or very little use	189	2.6	0.65	0.05	-
Somewhat or high use	189	2.5	0.66	0.05	

*Differences between the groups are significant (p<0.05). IBL: Inquiry-based learning, SD: Standard deviation, SE: Standard error

[t(227)=−1.896, p'=0.118] subscales of TE. On average, student engagement was 0.178 points higher after the training program (Cohen's *d* value 0.16).

To further analyze the efficacy-enhancing effects of training, a change score was calculated for the participants (subtracting pre-test score from the post-test score). Kruskal–Wallis one-way ANOVA or Mann–Whitney U-test was used to determine whether the change in the TE score is related to specific prior characteristics. It was found that teachers experience as a teacher ($\chi^2(2)=0.810$, p=0.667) or prior use of IBL (U=5616.5; p=0.096) is not related to the effects of training. It was found, however, that the change was notable for teachers with lower average TE (mean rank=85.3) at the start of the training than for those with higher average TE (mean rank=143.2), U=3197.5, p<0.001.

Effects of Training on Perceived Restrictions of Using IBL

After having an opportunity to try IBL in the classroom and completing the training, teachers' perception of the difficulties decreased, as revealed by the paired samples T-test. The effect of the training was most significant for the perceived lack of resources, t(227)=6.665, p'<0.001; difficulties managing the classroom, t(226)=4.087, p'<0.001; and overcoming students' lack of motivation, t(209)=−3.489, p'=0.003. The training had no significant effect on the preconception about the high knowledge dependence, t(209) = 2.102, p' = .074; or the sense of systemic restrictions, t(227)=0.557, p=0.578. Corresponding Cohen's *d* effect sizes can be found in Table 8.

DISCUSSION

IBL has been recommended as an effective method to be used in classrooms (Rocard et al., 2007) with the aim to raise interest in STEM subjects and careers, which is one of the top priorities in current educational policies across Europe (Kearney, 2016). However, there seems to be a gap between what is written in the curricula and what goes on in the classrooms because IBL is not used by the teachers as much as expected by the

Table 7: Attitudes toward IBL among teachers with high and low teachers' sense of efficacy

Subscale	N	M	SD	SE	Cohen's *d*
Knowledge dependence*					
Low teacher efficacy	178	2.4	0.70	0.05	0.33
High teacher efficacy	171	2.1	0.70	0.05	
Motivation*					
Low teacher efficacy	178	2.9	0.58	0.04	−0.28
High teacher efficacy	171	3.0	0.62	0.05	
Resources*					
Low teacher efficacy	200	2.6	0.61	0.04	0.32
High teacher efficacy	182	2.4	0.66	0.05	
Classroom management*					
Low teacher efficacy	200	2.3	0.56	0.04	0.73
High teacher efficacy	181	1.9	0.51	0.04	
Systemic restrictions*					
Low teacher efficacy	200	2.6	0.62	0.04	0.39
High teacher efficacy	182	2.4	0.67	0.05	

*Differences between the groups are significant ($p<0.05$).
IBL: Inquiry-based learning, SD: Standard deviation, SE: Standard error

Table 8: Changes in attitudes toward IBL after the training (only significant changes are shown) positive value indicates an increase after the training

Subscale	Cohen's *d*
IBL is suitable for increasing student motivation	0.277
Resource restrictions	–0.359
Classroom restrictions	–0.303

IBL: Inquiry-based learning

policymakers (Capps and Crawford, 2013a). This is why successful adaptation of the inquiry approach is still a popular research topic. We still have many teachers who have not received sufficient training on the inquiry approach and need support with adopting this method into their teaching, although prior research has shown that teacher training is an effective way to introduce inquiry in a science classroom (e.g., Ertikanto et al., 2017; Perez and Furman, 2016) and help to overcome different barriers related to adoption of IBL.

After a thorough literature review about teachers' professional development concerning the implementation of IBL in science education, we identified the key roles that a teacher needs to undertake for a successful training, namely, teacher as learner, teacher as thinker, and teacher as reflective practitioner. We developed a new training program focusing on introducing IBL to science teachers. This particular program was developed in the context of the Ark of Inquiry project and validated through research. In these training sessions, the teachers had the opportunity to (1) experience IBL as their students would, (2) receive information on the theoretical and empirical underpinnings of IBL and on possible resources that can be used for inquiry-based teaching and learning (such as the Ark of Inquiry web platform), (3) design and implement their own IBL materials or implement existing IBL materials from the Ark of Inquiry web platform in their science classes, and (4) later reflect on these implementations in the presence of their fellow teachers.

As teachers' beliefs are significant predictors of adopting new methods (Voet and De Wever, 2017; Tschannen-Moran and Hoy, 2001), we wanted to know whether this training program would have an effect on TE, which is a more general belief and attitudes toward inquiry, that is more specific. More specifically, we had the following three research questions:

1. Is prior use of inquiry and teaching experience related to teachers' attitudes toward inquiry?
2. Is TE related to attitudes toward the inquiry approach?
3. Do the teacher training sessions have an impact on TE and attitudes toward inquiry, and if so then in which areas, is it more pronounced?

The Relationship between Previous Experiences and Attitudes toward IBL

Similarly to Xie and Sharif (2014), we found that attitudes toward IBL were not related to teaching experience. Thus, teachers' experience in itself is not sufficient to adopt new methods, such as IBL. In the context of teacher training sessions, this suggests that there is no reason to concentrate on specific groups based on teaching experience.

Prior use of IBL was related to attitudes toward IBL. Teachers who had used IBL 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 IBL is suitable for motivating students and is not a highly knowledge-dependent method. They also believed that this method is not more challenging regarding classroom management. However, there was no difference between groups related to 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 toward IBL go hand in hand with first-hand experiences, emphasizing the importance of practical components in trainings.

The Relationship between TE and Attitudes toward IBL

We found that teachers with a higher sense of teacher efficacy have more positive attitudes toward IBL even before the training sessions. The relationship was the biggest related to the attitude concerning classroom management when using IBL. This may be explained by the fact that one subscale of TE is related to classroom management; therefore, it makes sense that there is a strong relationship between the two. This means that teachers with a higher sense of efficacy are more confident about their classroom management skills and this applies also to classroom management in the context of IBL lessons as well. Tschannen-Moran and 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.

The Effects of the Teacher Training Sessions

When comparing the pre- and post-questionnaire data, we found that TE and attitudes toward inquiry were generally higher after the training sessions, which indicates a positive effect of the training. If we compare the training within our project to other trainings that have been found to be effective, we see that they have some mutual elements such as authentic experience, opportunity for reflection, and opportunity to gain new knowledge (Papaevripidou et al., 2017). Within the TE subscales, the only significant effect was in the Student Engagement subscale. This can be explained by the fact that inquiry is supposed to engage students more compared to traditional teaching (de Jong, 2006; Pedaste et al., 2013). It may be that the teachers had positive experiences with IBL, which in turn impacted their general belief of how well they can engage students. Furthermore, they were now equipped with a new method for better engaging different students.

The attitudes toward IBL were also more positive after the training sessions. 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 make different inquiry activities. After the training, there was a decrease in the view that the classroom is difficult to manage during IBL lessons. Furthermore, teachers now found to a greater extent that inquiry is suitable for motivating students. The change in these attitudes may be not only due to greater knowledge gained in the training but also the experiences with IBL in their classroom. However, the attitudes toward knowledge dependence and systemic restrictions did not change. This latter is to be expected because these attitudes not only cannot be tackled with trainings if they are real but 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 the skill that is evaluated. How to change systemic restrictions, real and perceived, seems to be a challenge, we still have to face. However, 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 are a potential way to overcome systemic restrictions.

As the Ark of Inquiry project is international, we had the opportunity to collect data from several countries. Thus, our sample was relatively big, and we saw that the positive effects were apparent even in such a diverse sample. Nevertheless, there are some limitations to our research. First, our study did not include a control group, and therefore, we do not know whether similar results would have emerged in a purely theoretical training course. Second, we saw a dropout of participants during the study which means that we could draw or conclude based on only these teachers who completed both pre- and post-questionnaires. Furthermore, we do not know whether the positive effects we see are stable and actually carry over to the classrooms. For example, Voet and De Wever (2017) found that training had a positive effect on pre-service teachers' IBL-related attitudes, but their teaching experience during the internship following the training had a negative effect. This may be different for in-service teachers. Therefore, more longitudinal studies are needed to know if and how the positive effects of the training carry over to teaching practice. Furthermore, it is not clear whether the training has an effect on both general (TE) and specific beliefs (attitudes toward IBL) or one is mediated by the other. Further studies could also incorporate specific IBL-related efficacy. Although we had a considerable sample with participants from 10 different countries, we cannot consider our sample representative, as the teacher training courses were voluntary-based and the number of participants varied between countries, and thus, some countries may have had a stronger effect on the results. Further research is needed to find whether there are differences between the countries, and if yes, then what the cause of these may be.

Further research would also benefit from an improved scale for measuring attitudes toward IBL. The scale in this research was a part of a scale used in a similar project implementing the inquiry approach (Dorier and Maaß, 2012). Unfortunately, in our study, the scales of the instrument did not result in as good internal reliability as in the original study, as the Cronbach's alphas were rather low. This is also a significant limitation of our study. We considered the possibility that this was due to the small number of items (2–4 items) in the scales that resulted in low Cronbach's alphas. To overcome this, we used mean inter-item correlation that has been suggested as an internal reliability estimate in case of low number of items in the scale (Briggs and Cheek, 1986). We found that the mean inter-item correlations were in the optimal range (0.2–0.4) suggesting that the scales are indeed unidimensional despite the low Cronbach's alphas.

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 et al., 2017). We also conclude from the results that this program can be used for groups with different amounts of previous experience as a teacher. Although the training was quite minimalistic, consisting of workshops lasting for 2–3 days and an assignment between the workshops, it incorporated significant elements that enabled the change in TE and attitudes toward IBL. When training in-service teachers, it is important to take into account that highly time-consuming training may not be suitable for them, and the cost-effectiveness of the training is also a factor to be considered.

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