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 (PKK) to realize (scientific) inquiry learning. Complementary to Pedagogical Content Knowledge they define PKK 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 PKK 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 PKK 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.

ACKNOWLEDGEMENTS

This study was conducted in the context of the European project "Ark of Inquiry: Inquiry Awards for Youth over Europe," funded by the EU under the Science in Society theme of the 7th Framework Programme (Grant Agreement 612252). This document does not represent the opinion of the EU, and the EU is not responsible for any use that might be made of its content.

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