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SCIENCE TEACHERS' PERCEPTIONS OF THE EMERGENCE OF RESPONSIBLE RESEARCH AND INNOVATION IN SCHOOL

Mirjam Burget,
Emanuele Bardone,
Margus Pedaste,
Katrin Saage

Abstract. *Responsible Research and Innovation (RRI) has recently gained wider importance in the European Union (EU) as an emergent framework informing the governance of science. While a growing body of literature describing RRI and its main conceptual dimensions has appeared in the last seven years or so and in several policy documents, the European Commission has emphasized the need to promote science education in the RRI context. However, there is no theoretical elaboration of how RRI can be meaningfully integrated into the practice of science education. In order to address this problem, the present research aimed at inquiring into the way in which science teachers make sense of RRI in school. Data were gathered with individual semi-structured interviews from 29 science teachers working in comprehensive schools and hobby schools. Abductive content analysis combining data and conceptual dimensions of RRI was used. In the light of how the science teachers in our sample have made sense of RRI, four theoretical categories have emerged: (1) meaning making; (2) taking action; (3) exploring; and (4) inclusion. These findings have important implications for developing a theory of RRI which can be beneficial for researchers as well as teachers for meaningfully integrating RRI into science education.*

Keywords: *abductive content analysis, responsibility as care, Responsible Research and Innovation, science education, science teacher.*

Mirjam Burget, Emanuele Bardone, Margus Pedaste
University of Tartu, Tartu, Estonia
Katrin Saage
Tartu Art School, Tartu, Estonia

Introduction

In the 21st century we live in the era of great challenges, which has led to greater interest in research and innovation. Responsible Research and Innovation (RRI) has become an important part of EU's research and innovation policy, first of all in connection with EU research and innovation programme Horizon 2020 (Forsberg et al., 2015), where RRI is developed as a political framework in the governance of science. From an administrative standpoint, the aim of RRI is described as cooperation of different parties in the research and innovation process in order to respond to the needs and values of society (European Commission, 2013). Similarly, RRI is defined in the academic literature as 'an attempt to govern the process of research and innovation with the aim of democratically including, early on, all parties concerned in anticipating and discerning how research and innovation can or may benefit society' (Burget, Bardone & Pedaste, 2017; p. 9). The theoretical core of RRI is then described by four conceptual dimensions, namely, inclusion, anticipation, reflexivity and responsiveness (Stilgoe, Owen & Macnaghten, 2013), to which Burget and colleagues (2017) added two emerging ones: sustainability and care. The role of conceptual dimensions is to specify the general RRI framework and to enable people to understand the conceptual implications of RRI. The RRI dimensions are characterized as follows: (1) *inclusion* is defined as engaging various stakeholders (civil, governments, researchers and businesses) in the research and innovation process (Asante, Owen & Williamson, 2014; Felt, 2014); (2) *anticipation* means estimation of the long-lasting influences of research and innovation achievements (te Kulve & Rip, 2011; Owen, Macnaghten & Stilgoe, 2012); (3) *reflexivity* refers to reflecting on the needs and values of society (Forsberg et al., 2015; Stilgoe et al., 2013; Wilsdon, 2005); (4) *responsiveness* denotes responding to the needs and values of society (Maynard, 2015; Schaper-Rinkel, 2013); (5) *sustainability* refers to establishing and preserving the conditions where humans and nature can exist in concord and which allow fulfilling the social, economic and other demands for current and future generations (Brundtland, 1987);

and (6) *care* means that decisions go along with the public domain so that people by themselves are responsible for the actions and decisions that are carried out on their behalf (Adam & Groves, 2011).

RRI in Education

The European Commission has proposed six keys of the RRI framework, where science education is one of the keys listed (Responsible Research and Innovation, 2012). In their studies, various authors (Blonder, Zemler & Rosenfeld, 2016; de Vocht, Laherto & Parchmann, 2017) have shown RRI in the light of the six keys proposed by the EU ('Regulation (EU) No 1291/2013', 2013). These six keys partially overlap with the aforementioned RRI dimensions (Burget et al., 2017). Another four dimensions or keys have been proposed in an evolving analytical framework of Heras & Ruiz-Mallén (2017). When compared with the RRI dimensions, the keys proposed by Heras & Ruiz-Mallén (2017) include the dimensions of reflexivity and inclusion. Neither the six keys proposed by the EU nor the evolving analytical framework by Heras & Ruiz-Mallén directly concern the RRI dimensions of responsiveness, anticipation, sustainability and care.

Concerning EU politics and research and development activities of the projects, there have been attempts to connect RRI to science education through various methods and approaches such as Inquiry-Based Learning (Bardone, Burget, Saage & Taaler, 2017; Ješková et al., 2016; de Jong, Lazonder, Pedaste & Zacharia, 2018; Pedaste et al., 2015b; Yang & Park, 2017), Education on Socio-Scientific Issues (Blonder, Rap, Zemler & Rosenfeld, 2017; Evagorou & Puig Mauriz, 2017), Socio-Scientific Inquiry-Based Learning (Ariza, Abril, Quesada & García, 2014; Blonder et al., 2017), Citizenship Education (Stilgoe, Lock & Wilsdon, 2014), Citizen Science (Stilgoe et al., 2014) and Nature of Science (Bardone et al., 2017; Heras & Ruiz-Mallén, 2017; de Vocht & Laherto, 2017); but also by praxis-oriented, problem-based and real-world learning (Tassone et al., 2017). Due to the higher level of engagement and cross-curricular nature of RRI, it has been suggested that RRI is integrated into science education through informal learning (Bardone et al., 2017; Gorghiu, Anghel & Ion, 2015). To sum up, previous studies have tried to elaborate the concept of RRI through the existing approaches but have not connected it explicitly to the RRI dimensions.

Taking into account the definition of RRI, it can be said that the aim of RRI is to form citizens of the future society who can take responsibility for their actions (Bardone et al., 2017). Therefore, the current research is paying more attention to responsibility. Here, the meaning of responsibility should be explained: on the one hand, responsibility means 'liability' or 'accountability' (Lucas, 1996) and, on the other hand, 'care', which refers to understanding humans as 'caring' people who can take the responsibility by themselves (Adam & Groves, 2011; Bardone et al., 2017; Bardone & Lind, 2016; Noddings, 2005). In education, care is considered as providing learners opportunities to care for the future in research and innovation practices (Tassone et al., 2017), or – on a more analytical level – making sense of RRI in science education (Barone et al., 2017). Therefore, this research offers some important insights into how to understand the conceptual framework of RRI in practice and how to make the framework relatable to education without providing concrete instructions to science teachers on how to 'do RRI' in school (Bardone et al., 2017).

Research Problem

RRI has been seen as the main approach in guiding the research and development process in the future, but in this case, science education in schools should also change. However, it is not known what changes are needed, as there are no studies about application of RRI principles in science education classrooms today. This research focuses on filling this gap. In order to integrate RRI effectively into education, future citizens should be aware of the challenges of today's society and familiar with the nature of RRI (Owen et al., 2012). The EU has also emphasized the need to promote science education in the context of RRI (Responsible Research and Innovation, 2012). On the basis of literature it can be said that RRI should be considered more widely than allowed by various previous methods and approaches and conceptualized more significantly in the educational context (Bardone et al., 2017; Heraz & Ruiz-Mallén, 2017; de Vocht & Laherto, 2017;). Therefore, theoretical elaboration of how RRI can be meaningfully integrated into the practice of science education is necessary. In order to make the RRI conceptual framework relatable to education and thus establish meaningful connections between RRI and education, it is necessary to understand how science teachers make sense of *research, innovation* and *responsibility* as well as RRI dimensions in the school context.

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Research Focus

The current research attempts to inquire into the way in which science teachers make sense of RRI in school, show which meanings science teachers attribute to the terms *responsibility*, *research* and *innovation* and also how RRI dimensions emerge in school from science teachers' point of view. The key research questions in this research are as follows: (1) How do science teachers perceive research, innovation and responsibility in school as part of the RRI conceptual framework? (2) How do science teachers perceive the emergence of RRI dimensions in school as part of the RRI conceptual framework?

Methodology of Research

General Background of the Research

The current research was qualitative in nature with an aim to figure out how RRI can be meaningfully integrated into science education. Individual semi-structured interviews were conducted to answer the research questions; the interviews were analysed using abductive content analysis. The interviews were conducted during the period of October 2015 – March 2018.

As this research used a qualitative approach, first, a description of the researchers is provided, which allows getting acquainted with the researchers' background, as is suggested for qualitative studies (Levitt et al., 2018). The first three authors have elaborated the concept of RRI by publishing RRI-related articles (Bardone et al., 2017; Bardone & Lind, 2016; Burget et al., 2017). The same authors have developed the concept of RRI in the EU project Ark of Inquiry, which aimed to promote inquiry-based learning and raise 7–18-year-old learners' awareness of RRI (Pedaste et al., 2015a). The authors contributed to developing the concept and carried out in-service trainings for science teachers in order to include the science teachers in RRI activities in education. The last author of the research has previously contributed to developing the framework of RRI (Bardone et al., 2017) and was involved with an aim to include the view of a practising teacher in the current research.

Sample of the Research

A total of 29 Estonian science teachers voluntarily participated in the research: 24 women and 5 men with the age range of 24 to 64 years. The interviewed teachers had been practising teachers for 1–32 years (13 years on average) and taught learners aged 7–18. Nineteen science teachers taught in basic school (learners aged 7–15), five in upper secondary school (learners aged 16–18), one in both basic and upper secondary school, and four in hobby school (learners aged 7–18). According to the Estonian Hobby Schools Act § 3, a hobby school is an educational institution which provides a basis for the acquisition of hobby education of youth for diverse personal development, including the practice of native language and culture (e.g., nature houses, music schools). Some teachers in the general education system followed a particular curriculum (e.g., Waldorf school or International Baccalaureate). The following subjects were taught: biology, geography, chemistry, physics, basics of research, and environmental studies. Most teachers taught in Estonian, but one teacher taught in English.

As the current research is qualitative aiming to collect examples of teachers' practices with maximum variation, the maximum variation sampling method was used (see Patton, 1990; Patton 2002). The main variations that were taken into account in the current research were a) various types of schools (comprehensive schools and hobby schools), b) teachers who taught learners in different ages c) locations of schools (rural and urban schools).

The snowballing and convenience-based sampling techniques were combined in the current research in accordance with the maximum variation sampling method. The researchers involved teachers they knew already as well as their acquaintances and previous colleagues who met the criteria of the sample. In addition to that, the following teachers were involved: those who were associated with the projects of the research group where the authors of this research were working, and those who were included through visits to nearby schools. The earlier relationships the authors had with some teachers facilitated the process of finding participants and enabled free conversations on the topics. The authors of the research did not identify any ethical dilemmas concerning including teachers the authors already knew. Most science teachers who participated in the research had no previous experience with the concept of RRI: only a few of them had previously heard of the concept.

An additional criterion for the selection of the sample was that the science teacher practises inquiry-based learning. The criterion was necessary, because in inquiry-based learning, a learner is given the opportunity to take ownership of the process, which is translated as a way to 'do RRI' (Bardone et al., 2017). Inquiry-based learning has been part of Estonian national curriculum since 2002 (Põhikooli ja gümnaasiumi…, 2002) – all formal education teachers who participated in the research followed the national curriculum. In hobby schools, teachers did not follow the national curriculum: the curriculum was mainly developed by the teacher. It was made clear to researchers that both the hobby school curricula and other curricula contained inquiry-based learning and teachers were actively using it in practice.

Instrument and Procedures

Semi-structured and open-ended interview was used in the current research. Before the main research, a pilot study was conducted with three science teachers. The aim of the pilot study was to practise the interview technique and to select the questions appropriate for the current research. Prior to the final interview plan, the interview questions were discussed with the authors of the research in order to form the final interview questions. The questions were modified so that the wider meaning of *responsibility*, *research* and *innovation* would be considered, following with the teachers' perception of the concept of Responsible Research and Innovation and the RRI dimensions (Table 1).

Table 1. Examples of interview questions in accordance with the research questions.

Research question	Example question in the protocol	Examples of clarifying questions
How do science teachers perceive research, innovation and responsibility in school as part of the RRI conceptual framework?	How can science be brought to school?	When you teach children, how much do you use science in school? How do you practise inquiry-based learning?
How do science teachers perceive the emergence of RRI dimensions in school as part of the RRI conceptual framework in school?	Reflexivity can be interpreted as discussing the values, needs and problems in society. How does reflexivity appear in school?	How do you offer children topics for discussion? Which discussion topics have children brought to class?

The way in which the interviews were carried out was always the same: the interviewer and the interviewee were the only people present during the interviewing process. The interviews began with a short introduction explaining the aim of the research and its ethical principles. The aim of the first part of the research (Appendix A, I) was to find out the meaning that science teachers give to the terms *responsibility, research* and *innovation* and how the concepts can be implemented in school. Secondly, teachers were asked about their perceptions of the concept *Responsible Research and Innovation* in the school context. The aim of the second part of the research (Appendix A, II) was to ask about teachers' perceptions of RRI dimensions in the school context. The interviews were conducted first with 20 teachers (questions about the terms *responsibility, research* and *innovation* and *responsible research and innovation* in Appendix A, I), then with 10 teachers (questions about and definitions of RRI dimensions in Appendix A, I and II). After that, additional data were collected from the same 20 teachers (definition of RRI dimensions in Appendix A, II). The first interviews with 20 teachers indicated that the concept of RRI should be considered more deeply, and, therefore, the next interviews incorporated the RRI dimensions, which gave a broad-based view of the concept from teachers' perspective.

The researcher posed the same questions to all interviewees, but, at the same time, the interviews were also flexible. The additional questions asked were as open as possible so that the interviewees could choose the appropriate viewpoint and the answers would not be influenced in any way. Only in questions about RRI dimensions, examples were given when teachers did not understand the meaning of a dimension. During the interview the interviewer reflected the answers of the interviewees, which helped to keep the flow of the interview and to make the answers more clear to the interviewer. To develop the topic, additional questions were asked in order to better understand if the interviewer understood the interviewee correctly. The topic was also developed particularly from the angle of RRI dimensions – for example, if the interviewee was talking about inclusion, the interviewer tried to develop the topic from this viewpoint.

The interviews lasted from 31 to 132 minutes (70 min on average). All interviews were recorded. When similar patterns started to appear and the saturation point was reached, no additional data were gathered. The interview

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recordings were partially transcribed: the first 20 interviews were fully transcribed (McLellan, MacQueen & Neidig, 2003) and the rest of the interviews were analysed in audio format. After transcribing and analysing the 20 interviews, similar patterns started to emerge, and, therefore, selective transcription was employed for the rest of the interviews (Gilbert, 2001). The interviews were listened to in full several times, and the relevant passages were transcribed: this was regarded essential for confirming the categories based on the research questions.

Data Analysis

Abductive content analysis was used for the research. As noted by Timmermans and Tavory (2012, p. 174), abductive analysis aims at 'generating novel theoretical insights that reframe empirical findings in contrast to existing theories'. Therefore, abductive analysis contains elements that have not been formerly included in the theory and allows creating a new interpretation of the phenomenon, comparing the findings with existing theory. Abductive analysis is suitable for the current research, as the RRI dimensions have been defined in academic literature, but in other disciplines than education. Abductive analysis helps to see the data through the lense of the RRI dimensions, and, additionally, bring up new interpretations of the phenomenon in the field of education.

For the current research, the conceptual framework of RRI was derived prior to the abductive analysis (Figure 1; 0). The abductive reasoning started from a point where the data collected from the interviews did not go along with the prior conceptual framework (see e.g., Dubois & Gadde, 2002; Kovács & Spens, 2005). The continuous flow between the empirical and theoretical world started to find a 'matching' framework (Dubois & Gadde, 2002; p. 556) that means: the empirical data (Figure 1, 1) was observed through the lense of RRI dimensions (0) which led to theory matching (2). The process finished with a theory suggestion (3): the categories and subcategories in the current research.

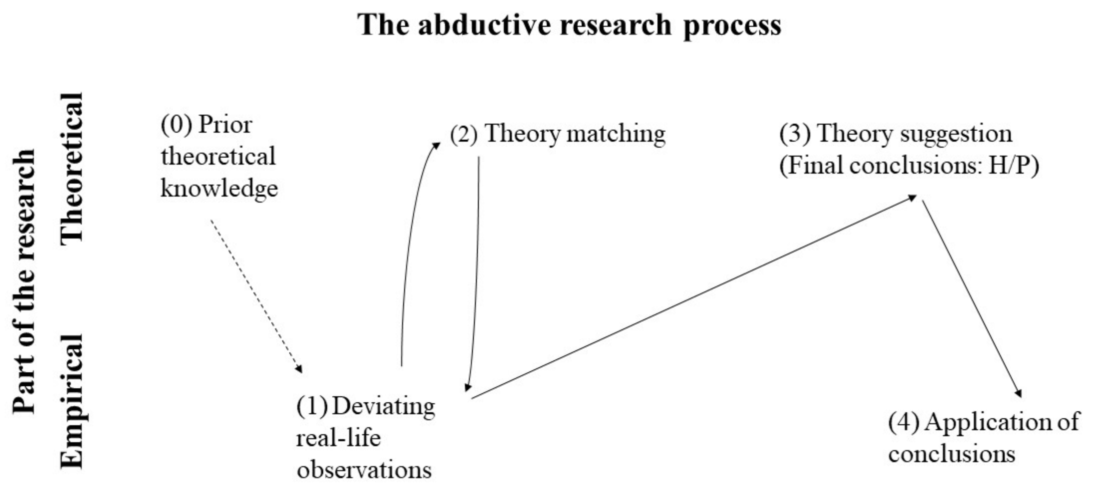

Figure 1. The abductive research process (Kovács & Spens, 2005).

An analytic schema was created before the analysis which included the six RRI dimensions. The data were coded both by two researchers, working independently, and discussed together after the process of forming categories. In analyzing the data, attention was paid to how RRI appears in school, at the same time taking into account the *responsibility as care*. The aspect of *responsibility as care* appeared in a previous research (Bardone et al., 2017) and was considered as a way of interpreting RRI in science education. In the analysis, all answers connected to everyday school activities where the aspect of responsible research or responsible innovation was not considered were left out of the research. Additionally, those general opinions of teachers that were not connected to the everyday activities at school were not considered in the research. Both authors identified comparable categories. Unclear conceptions were reread and rephrased until consensus was achieved. In addition, discussions were held together with three or four researchers in order to analyse the comprehensibility and logic of the categories. After labelling and describing the categories, the transcripts were read and the recordings were listened to again in order to complete the analysis.

Results of the Research

The data analysis indicated that RRI appears in school in the following ways:

1) meaning making
   (1a) responsible collection of scientific information and discussion
   (1b) taking into account ethical considerations in research
2) taking action
   (2a) responding to the needs and values of the community
   (2b) considering the importance of the environment
   (2c) considering the importance of equipment
3) exploring
   (3a) carrying out explorations in science lessons
4) inclusion
   (4a) teachers and learners
   (4b) learners within one class
   (4c) teachers and learners inside and outside the classroom
   (4d) cooperation between teachers
   (4e) teachers, learners and parents
   (4f) teachers, learners and specialists/researchers

In the next paragraphs the rationale for formulating the categories is given. The results are presented in categories and subcategories. In order to illustrate the text, examples from the interviews are included. The quotations were slightly edited to decrease the amount of filler words and repetitions. Numbers were used in order to protect the identity of the interviewees.

Meaning Making

Meaning making can be characterized as collecting information responsibly, discussing and reflecting on the questions or problems in research (and innovation) and taking into account ethical consideratons concerning research in school.

Responsible Collection of Scientific Information and Discussion

The sources that teachers brought out and where they got their information were popular science in nature; only some teachers – especially teachers who taught 15–18-year-old learners – declared they used scientific resources in school. As one interviewee said:

> */.../ but last year, there was /.../, whatever the magazine is called, not ... Science Illustrated, that's it. It had a story about these DNA boxes, you know, and then we tried to understand how they work /.../, it [these topics] usually comes from the topics of these usual popular magazines, right, they [learners] don't read this deep science anyway, right, but the kind that is a simplified version, this kind still reaches the learners. (7)*

Only some teachers mentioned how they critically analyse the information before using it and which channels are more trustworthy than others. The informants reflected that pupils should learn how and where to find the suitable information and how to critically evaluate the information before using it.

In addition to finding the sources, teachers pointed out that the results of research cannot be brought to the classroom word for word and that learner' age should be taken into account. Here, the higher responsibility rests with the teacher. Particularly teachers who taught grades 1–6 were cautious about bringing research topics

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directly to the classroom. Attention should be paid to maintaining learners' interest and making sure that research is not too forced. Additionally, the current theme raised the issue that necessary topics should not be left out when teaching learners, otherwise they might not later understand the science topic.

The knowledge teachers got from popular science or scientific resources was used in teaching: for example, to get learners' attention; to introduce the topic; to open up the problem; or the information was used in discussions. In order to carry out the discussions, teachers encouraged learners, already at a young age, to read the newspapers, popular science sources or scientific articles and urged them to share the news with each other at school. For instance, in one school, knowledge is shared in 'morning circles' that take place every day before the lessons. Such practice gives the learners the chance to share the news immediately after reading them and to compare and contrast the information with others. The informants emphasized that when learners read, the discussions are also more lively.

Learners like to read when they are interested in a topic. The interviews revealed that when learners are interested, their sense of responsibility also increases. Some teachers stated in their interviews that when learners were more interested in some science-related topics, the teachers elaborated the discussions based on learners' interest and also valued learners' own initiative to discuss or bring up problems. Some teachers even admitted that it was not a problem for them to discuss themes during the lesson that they had not planned ahead but that learners found interesting and could learn from.

Taking into account ethical considerations in research

The ethical aspects were considered spontaneously as cross-curricular topics. Topics such as irresponsibility in research and ethical considerations in research and innovation in general were under discussion in this subcategory.

Discussions about RRI and how to practise it in school often led to the topic of irresponsibility or unethical aspects in research. Considering irresponsible research (and innovation), teachers described how unreliable data has entered the school and their reactions to it. The examples included how learners have brought along articles from unreliable sources; thus, teachers stressed the importance of discussing source reliability. In order to avoid unethical behaviour, teachers introduced to learners' trustworthy sources where they could find reliable data. In teachers' opinion, it is important to be critical and not trust the data until proven reliable. The informants also mentioned discussions where they brought out negative aspects of research in the past. However, the informants did not elaborate on the topic of teaching the methods of critical analysis of data and resources.

Ethical considerations in research in general were also discussed. The examples included discussions about unethical studies or argumentation about unethical behaviour of scientists. For example, one interviewee argued as follows:

> *It's very important, because when it turns out that scientists have done some irresponsible things or have lied about something or manipulated the data, then people's faith in science decreases and it's more difficult for me as well to talk about it convincingly […]. (3)*

The ethical usage of digital devices was another topic that emerged from teachers' answers. Teachers said that they assign tasks to be carried out on digital devices only moderately and brought out that using a lot of digital devices would get learners stuck to their screens and make them too passive.

Turning to the research activities in school, the ethical aspect concerning conducting research appeared. Experiments have to be safe both for the teacher and for the learners. Informants emphasized that learners should not get injured and the equipment should not be damaged when doing experiments.

Taking Action

Concerning taking action, the aspects of responding to the needs and values of the community and considering the importance of the environment and (technological) equipment in carrying out the research activities were brought out. Taking action requires taking into account the environment and the equipment necessary for research activities, as action cannot be taken effectively without these components.

Responding to the needs and values of the community

When teachers were asked about responding to the needs and values of the community, a dichotomy appeared in their answers: some teachers valued learners' initiative to be responsive to various problems, whereas others found that learners should not be so responsive. Concerning teachers' responsiveness, teachers have organized research-based events or taken part in them together with their learners. This, in general, is a basis for learners to become responsible citizens.

Here, responding to the needs and values of the community can be compared to active citizenship. Some teachers found that learners should not be responsible and take action, because teachers or parents are responsible for them. At the same time, there were teachers who emphasized certain areas where responsibility was shared between the teacher and learners or where learners took the initiative themselves and were responsive to problems. Talking about this issue, an interviewee said the following:

> /…/ the learner starts ... they find it by themselves from their own surroundings, the problem that they want to, for example, investigate, that has sort of caught their eye in their own living environment, and when they take it up and start investigating, then they show, indeed, responsibility, I think. The things in the context of life, context of everyday life is what speaks to the child, the learner. (12)

As for learners as active citizens, teachers had different opinions. Some teachers emphasized that teachers have to 'push' the learners to do something and that learners rarely engage in something on their own. In other schools, opportunities and support to learners for carrying out activities was provided by the school administration. It is important to note that sharing responsibility depends on teachers: how they take into account the opportunities and the age of their learners.

The activities that science teachers had initiated themselves included various research-based events (e.g., conferences, project days, the Researchers' Night Festival, the World Week initiative). In one school, for example, teachers organize so-called project days where learners of different ages are given a number of tasks that they have to complete by themselves during a certain amount of time. This, in general, teaches learners how to be responsible. Another way to give learners the chance to take higher responsibility is to conduct research or creative work. In this type of work learners can choose a problem to solve by themselves.

In addition, teachers have encouraged learners to take part in citizen science: they mentioned certain citizen science projects their learners had participated in, e.g., Globe, or projects where data were collected about bird species. Some teachers admitted that learners were perceiving their own work as more valuable when the data were actually used in everyday practice and were therefore feeling a stronger sense of responsibility towards their activity.

Considering the importance of the environment

The environment for completing science activities comprises the space both inside and outside the classroom. Concerning the rooms inside, teachers found physical environment to be essential for learning: e.g., how the room looks like or if there is a laboratory in the school. In some schools, for example, there are innovative open learning rooms, which means that the classroom is built in a way that allows learners to take responsibility for their own learning.

It is possible to use the rooms inside for learning, but the learning process can also take place outside. Teachers whose school was situated in the countryside valued the environment around them and also carried out their lessons outside. The environment was valued more, as there were not so many opportunities to visit museums or science centres located in towns (owing to lack of time and financial resources). Teachers mentioned that teaching inquiry-based learning lessons outside is fine, but challenging, as an unknown environment requires more preparation.

Teachers found it important that learners contribute to the school's overall well-being. For instance, a teacher pointed out that both the teacher and learners are responsible for the climate they create in the classroom, a good athmosphere for learning. Additionally, one interviewee, when asked about taking responsibility, valued learners' actions on how to make the rooms in their school more useful, smart or beautiful and how to bring more science to school.

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Considering the importance of equipment

The equipment for carrying out research activities effectively at school is of significant importance and should be purposeful. There should be enough tools, the tools should be contemporary and in use. Here, lack of equipment was pointed out too. For instance, some teachers mentioned that it is not easy to teach when some equipment is missing, e.g., data projector or materials for an inquiry-based learning lesson, and that research cannot be done 'with pen and paper only'. Here, the responsibility of the school management in these issues was emphasized. However, the data revealed that teachers are creative – when a tool is missing it can be replaced with something else.

As for IT facilities, a variety of perspectives was expressed. The majority commented that a supportive IT environment and IT tools for learning are essential. Concerning technological equipment, teachers value tablets or other devices in the classroom and find them innovative. However, not all schools have digital devices for teachers and learners. To overcome the absence of computers, lessons have been carried out with learners' smartphones.

Concerning technological equipment, teachers were also concerned about their ability to use the devices. Informants mentioned fears that learners know more about computers than teachers. However, from the positive side, they mentioned that learners can teach them and this can raise learners' self-esteem and sense of responsibility.

Exploring

The third category – exploring – was characterized by carrying out explorations in inquiry-based learning lessons, taking into account how a teacher will share the responsibility with learners during the inquiry-based learning process.

Carrying out explorations in science lessons

An inquiry-based learning lesson can be viewed by some teachers merely as following the rules which lead to a certain conclusion, or by some other teachers as a creative process where the conclusion is also unknown for the teacher (Bardone et al., 2017). For instance, a teacher described a process of inquiry-based learning where both the teacher and learners reached the point where they could not explain what exactly happened. This, in general, gives both the teacher and learners the chance to make discoveries.

The most interesting finding in the current research was to see how science teachers paid attention to responsibility in inquiry-based learning lessons. Explorations are appealing to learners and learners want to act to carry them out. It was important for some teachers that learners take responsibility for the entire research process that they were engaged in. Prior to the inquiry learning process, teachers created the conditions so that learners could take the responsibility. The innovative results of the research work can be shared with a wider audience, which also makes the research work more meaningful for learners.

Some interviewees argued that when learners are interested they also feel the responsibility. Teachers believe that in this way, learners will reach better results in their research work. When there is more room left for responsibility, both learners' interest as well as ownership of the work will grow. Research work in school allows learners to know some topics more thoroughly and understand more about the nature of science. For example, one interviewee said the following:

> *[…]I let learners, when they're doing an experiment, choose all things themselves and then it's so weird that then their attitude does indeed completely change, for example, when I tell them that for an osmosis experiment, pick all concentrates yourself, that it's not a big deal if the experiment doesn't work out because you chose the wrong concentrations. Then they have a totally different attitude, because then they have made all things by themselves […] they feel that they are responsible, that it was their experiment, that they are interested in the result and they understand that it was their work. (3)*

When responsibility increases, learners' motivation will also grow and learners work more productively. Higher responsibility allows learners to choose which research work or experiments they want to carry out. When learners take the initiative, they will also care more about the topic. It was mentioned that there should be even more chances for learners to decide which experiment to perform. Additionally, it was pointed out that sometimes school rules do not enable doing certain experiments and that the possibilities of doing experiments should be negotiated between teachers and learners.

Inclusion

The fourth category of RRI was related to inclusion and means involving various parties in the research and innovation process. The category *inclusion* was devided into six subcategories: 4a) teachers and learners, 4b) learners within one class, 4c) teachers and learners inside and outside the classroom, 4d) cooperation between teachers 4e) teachers, learners and parents, and 4f) teachers, learners and specialists/researchers. Concerning the category *inclusion*, the relationships between different parties were observed. Teachers pointed out that inclusion is working well with earlier contacts and that the support of the school management is also important here.

The informants emphasized that all parties should be involved in the research and innovation activities and that here the higher responsibility lies on the teacher – how the teacher guides the process. In the cooperation between teachers and learners, teachers see themselves as facilitators of the process, but at the same time there are also teachers who view themselves as equal partners: teachers teach learners and learners teach teachers. Although it is possible to involve all learners at the same time in the research activities, it was mentioned that introducing research to a large number of learners differs from introducing research to smaller numbers of learners who are really interested. Learners who are more interested in the topic are more involved. However, when teachers are interested, they can include learners in science activities more easily.

Moving now to cooperation between learners in one class, inclusion is necessary, as research is not done alone. Inclusive practice between learners emerged by including learners in the research process in school. In this process the interviewees valued group work. Group work is an important part of increasing the sense of responsibility, as then learners understand that their work is connected to other learners' work. In groups, learners can create the conditions for synergy; they have to reach agreements on how to solve a problem together.

> /…/ responsibility is also, for instance, being in a group, making your contribution and not letting the people in your group down. And this is indeed the advantage of group work, that they learn to make their contribution, that they ... they can't really stay away much, because the others would disapprove. (12)

The cooperation between learners may emerge both between learners of the same class and between learners of different classes. A teacher mentioned here the so-called project days or one class teaching a lesson to another class, which were enjoyable for both younger and older learners. Cooperation between older and younger learners was encouraged with an aim to grow more caring citizens who would also understand each other. Cooperation with schools outside Estonia was mentioned, drawing a parallel with researchers, who have to communicate over long distances. In addition to that, hobby schools and hobby groups were mentioned, which enable involving interested learners of different ages. In some schools, teachers found cooperation between older and younger learners a good opportunity for learning, but in others (especially in large schools) still something that is not so easy to organize.

Turning now to cooperation between teachers, divergent discourses emerged. On the one hand, teachers valued cooperation between one another. They had planned project days or lessons together, participated in round tables, carried out lessons together via Skype, connected various subjects in one lesson or co-organized various events. Teachers found sharing ideas and discussions a good basis for innovative ideas. They also found that supportive groups and support by the school management are necessary. The cooperation between teachers included mainly science subjects, but some examples emerged where cooperation between subjects of 'soft' and 'hard' sciences had taken place. On another hand, cooperation with one another is sometimes challenging for teachers. Here, failures connected to the size of the school and finding common timeslots or common 'language' were brought out.

The data revealed that teachers had involved parents in several activities. Parents had been involved in inquiry-based learning lessons, where they saw how learners worked individually as well as together with other learners. As one interviewee said:

> *Whenever I do the day of learning hubs [Goodstart method], I have parents visiting, so it's hard for me to divide myself between four or five hubs. And the parents are usually happy to come, because then they see their children cooperating with others, they see their children, how they can work individually, how they can work in a group, how they come to those conclusions, it's a very good experience for the parent as well. (13)*

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The interviews revealed that teachers valued cooperation with parents, although in some examples it remained modest. When learners do their research work, teachers support learners' and parents' cooperation, because this way it is possible for learners to become more aware of their possibilities for a future career. In engaging parents, both the support of the school management as well as the school as a community are important.

Including specialists from outside the school is innovative in teachers' opinion; specialists can make a topic more meaningful for learners and help them understand that research is not done somewhere far away but close to us. For example, teachers have asked various specialists or researchers to come and visit their school. Teachers pointed out that cooperation with universities has occurred when learners have done their research work and that this is also encouraged by the teachers. Teachers have used the knowledge they have gained in their lessons and searched for cooperation possibilities with researchers in order to support learners' interests.

Inclusion outside the school environment is connected to various institutions. Teachers have visited laboratories with their learners. Visiting laboratories gives learners an overview of how research is done in reality. Teachers value visiting such institutions with their learners, as it gives teachers the chance to become more familiar with specialists' everyday work, integrate different subjects and offer learning opportunities to learners who are more interested in a certain subject. When learners visit different institutions, they will get a better overview of their future career possibilities. Teachers also commented that discussions between teachers and specialists are necessary before the visit so that welcoming institutions can bring out parallels with different subjects taught at school.

Science centres, museums and nature schools offer educational programmes for learners. Teachers admit that taking part in programmes enriches the learning process more than learning at school and that these lessons are more interesting for learners than normal school lessons.

In general, teachers are waiting for cooperation possibilities with various institutions and find that cooperation possibilities with institutions should be made easier for teachers. In addition to cooperation with institutions, the desire and need for creating a community of RRI was brought out.

Discussion

The current research tries to find the answers to questions of how science teachers perceive the emergence of research, innovation and responsibility and the dimensions of RRI as part of the RRI conceptual framework in their work. It appeared that all RRI dimensions emerged in the research, but most of them had to be translated into the language of science education. The dimensions *inclusion* and *care* appeared clearly and could be found among all other dimensions. In the current research, the dimension *care* was considered as a way of responsibility where teachers' or in teachers' view the learners are by themselves responsible for their actions (Adam & Groves, 2011). The dimension *sustainability* was left out of the research. Although teachers considered the aspects of sustainability, the area deserved to be studied in depth. The other three dimensions – reflexivity, responsiveness and anticipation – needed rephrasing, as in the school context they emerged differently than described in the conceptual framework.

Concerning the category *meaning making*, the research showed how a teacher can practise reflexivity with learners. A teacher can critically analyse the sources, develop the ability to discuss in the research and innovation process, but also recognize or bring up ethical questions if appropriate. According to our results, this is the meaning of *reflexivity* in school practice. So the school has to promote reflexivity at a feasible and relevant angle and thus develop learners' ability to be more reflexive as future citizens. In addition, it is obvious that teachers cannot bring reflexivity to school as it is stated in academic literature – reflecting on the values and beliefs during the research and development process (Wilsdon, 2005). Bringing the RRI dimension directly to school would be questionable especially for teachers who teach grades 1–6, as young learners might not understand research in this sense. The research showed that research activities with younger learners start with small inquiries and learners at this age are not able to see the far-reaching impact of research. Therefore, science teachers can consider how to treat reflexivity in school by analysing their practices and discerning to what extent the dimension needs to be more considered.

Considering the category *taking action*, the research revealed two topics. Firstly, the data revealed how responsibility for taking action is perceived or negotiated between teachers and learners, and, secondly, how a teacher perceives the responsibility for choosing the research-based activities, environment or equipment for learning. However, in academic literature, responsiveness is described as noticing and reacting to the problems or risks in society (Maynard, 2015; Schaper-Rinkel, 2013). Education is not obliged to deal with problems and risks in society but respond to the problems or needs in the school context. Therefore, teachers did not have a different conception as to what responsiveness in the school context means, but the difference rather occurred on the types of problems responsiveness was applied to. Teachers play an important role in taking responsibility for issues connected to bringing research and innovation to the school context and thus ensuring better conditions for carrying out research and innovation activities in school. The activities where learners took the lead were predominantly not science-based in nature but still serve as a basis for forming active and responsible future citizens who can also respond to the needs and values of society in research and innovation activities.

Anticipation in academic literature denotes adopting a future-oriented view that concerns opportunities or risks in research and innovation activities (te Kulve & Rip, 2011; Owen et al., 2012). In education the dimension is named *exploration* – the process where a learner takes the opportunity to explore for him- or herself what is unknown (Pedaste et al., 2015b). So the knowledge a learner will get is directed to the future – something that is unknown and needs to be investigated. In the field of education, anticipation can have another meaning: teachers' answers revealed that learners are ready to explore, but are not, especially the younger ones, able to analyse the forward-looking concerns or opportunities in society. Since exploration is less related to risk management, it places more emphasis on openness and discovery – both a distinctive trait of innovation. In the current research the exploration to inquiry-based learning was linked, as exploration is also treated as a core element in the inquiry-based learning process (Pedaste et al., 2015b). The inquiry-based learning method encourages learners to be active in this process in discovering something unknown for them and to take responsibility for their inquiries (Bardone et al., 2017; Pedaste et al., 2015b). It should be noted that implementing inquiry-based learning depends highly on how teachers interpret inquiry-based learning for themselves and how teachers perceive responsibility as a dynamical process. Letting learners take greater ownership of their work allowed learners to participate in a way of 'meaningful engagement', because they were given the opportunity to contribute and take the responsibility (Bardone et al., 2017, p. 303). Thus, giving learners the possibility to contribute in the inquiry-based learning process allows them to 'do RRI' in education (Bardone et al., 2017).

In this research, inclusion is not treated as including various parties in the research and innovation process at early stages in order to reach the socially desirable outcomes (Asante et al., 2014; Owen et al. 2012), as it appears in academic literature. Instead, the actual relationships were observed in and outside the school which would lead to the development of learners' cooperation abilities in the future. It is important to note that inclusion appeared in all categories of meaning making, taking action and exploring and can therefore be considered a central part of RRI. The principal question that teachers posed was about how to include the learners as well as various parties in the research process in school. It was evident that including various parties and therefore combining different disciplines was complicated for teachers. The same problems evolve between researchers concerning RRI (Felt, 2014). Including various parties in the school context requires at least three persons: a teacher, a learner and a specialist outside the school. Thus, a teacher as a carer cared for the learners as cared-fors (Noddings, 2005), trying to provide them with possibilities to acquire knowledge or work together with a specialist as a third party. Thus, teachers should make conscious efforts to overcome obstacles in combining different disciplines.

Conclusions

The aim of the current research was to find out how science teachers perceive the emergence of RRI in their work. RRI in education was conceptualized by the following four categories: (1) meaning making; (2) taking action; (3) exploring; and (4) inclusion. The research showed that the meaning of RRI dimensions in academic literature and the categories that emerged in the school context did not coincide unambiguously. However, a point of contact between the academic RRI dimensions and the empirical evidence of science teachers' perspectives was proposed. Thus, this research has demonstrated, for the first time, how the RRI dimensions presented in academic literature can be interpreted in the school context.

The limitation of the research was that data collection was done through interviews only. Triangulation of data would have provided a perspective that remained hidden in the current research – how teachers practise RRI in reality and which RRI dimensions appear in school. The next studies should be carried out involving other parties (e.g., learners, parents, researchers) together with teachers in the research process by conducting participatory research and observing the emergence of inclusion as part of RRI.

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This research has several practical applications. First, the results can form the basis of advice on possible changes in the national curriculum in order for education to better respond to the needs of the future society. Secondly, the content of RRI can be introduced in in-service courses provided by universities. In such courses, it is possible to show to teachers how their current practices are connected to RRI and which RRI aspects in education are not addressed yet and need more attention.

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Appendix A

I The questions in the semi-structured interviews about research, innovation and responsibility and responsible research and innovation

1) What role does science play in your everyday life?
2) How can science be brought to school?
3) What does innovation mean to you?
4) How can innovation be brought to school?
5) What does responsibility mean to you?
6) How can responsibility be brought to school?
7) What does responsible research and innovation mean to you?
8) How can responsible research and innovation be brought to school?

II The way RRI dimensions were explained to the teachers during the interview

1) Reflexivity can be interpreted as discussing the values, needs and problems in society.
2) Responsiveness can be explained as taking responsibility for the concerns or problems in a wider social context and taking appropriate action.
3) Anticipation means foresensing and preventing the long-term impacts of research and innovation outcomes.
4) Inclusion denotes including various parties in the research and innovation process at its early stages.
5) Sustainability is described as a development path where the needs and efforts of the current generation are covered without limiting the interests of the future generations.
6) Care is characterized by decisions that are connected to public interests and where a person is taking responsibility for own actions by themselves.

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Mirjam Burget	MA; Junior Researcher of Educational Technology; University of Tartu; Salme 1a, Tartu, Estonia. E-mail: mirjam.burget@ut.ee Website: https://www.etis.ee/Portal/Persons/Display/a3fd6446-22f5-47dc-9cb7-8a16ae5ea20a?lang=ENG
Emanuele Bardone	PhD; Senior Research Fellow in Educational Technology, University of Tartu, Salme 1a, Tartu, Estonia. E-mail: emanuele.bardone@ut.ee Website: https://www.etis.ee/Portal/Persons/Display/dc8572f5-4398-42f4-a0e5-799e84e79668?lang=ENG
Margus Pedaste	PhD; Professor of Educational Technology, University of Tartu, Salme 1a, Tartu, Estonia. E-mail: margus.pedaste@ut.ee Website: www.ut.ee/pedaste
Katrin Saage	MA; Biology and Chemistry Teacher, Tartu Art School; Eha 41, Tartu, Estonia. E-mail: katrinsaage@gmail.com