ORIGINAL ARTICLE

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

Emanuele Bardone[1], Mirjam Burget[1], Katrin Saage[2], Maarja Taaler[1]

[1]Institute of Education, University of Tartu, Estonia, [2]Miina Härma Gymnasium, Tartu, Estonia

***Corresponding Author:** bardone@ut.ee

ABSTRACT

Originally introduced in several policy documents issued by different institutions belonging to the European Union (EU), the term responsible research and innovation (hereafter RRI) has gained considerable attention in recent years among researchers coming from different backgrounds and disciplines. RRI constitutes an attempt to articulate a theoretical framework that would shape the governance of science in Europe. While science education is mentioned in various EU policy documents as one of its strategic dimensions, the way in which RRI can actually be translated into science education is a topic that needs empirical investigation as well as theoretical elaboration. The overall aim of the paper is precisely to offer that. In the present article, we posit that RRI in science education can be experienced meaningfully by linking it to inquiry-based learning, which already stresses the importance of active participation as well as students' responsibility for discovering knowledge. To see this potential connection in practice, we conducted an ethnographic study involving seven Estonian science teachers, who agreed to be observed at least 3 times when they conducted inquiry-based learning lessons in their school. Specifically, the study aimed at acquiring a better understanding as to the meaning that the term responsibility can have during the different phases of inquiry-based lessons. The results of the ethnographic study allow us to come to the conclusion that RRI can be interpreted in science education as a type of meaningful engagement in and for an inquiry during which the students are given the opportunity to make meaningful decisions in the different inquiry phases and thus be able to take responsibility for the inquiry process.

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

INTRODUCTION

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

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

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

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

Such conceptual and theoretical task can be empirically grounded by focusing on the practice of inquiry-based learning in the class: This is where students have the opportunity to have first-hand experience of getting in contact with something that bears some resemblance with what real scientists and researchers do and thus actively participate in producing knowledge (e.g., de Jong and van Joolingen, 1998; Chang and Wang, 2009; Bell et al., 2010; Madhuri et al., 2012; Gutwill and Allen, 2012; and Pedast et al., 2015). While the similarities with what researchers and scientists actually do (or are supposed to do) are merely analogical and sometimes a controversial matter (e.g., Hodson, 1998; Hodson and Wong, 2014), an inquiry is characterized by a number of phases, namely, orientation, conceptualization, investigation, conclusion, and discussion (Pedaste et al., 2015), during which students can pose and articulate research questions, elaborate conjectures and hypotheses, design and perform experiments, draw conclusions from the data collected, discuss and communicate their findings, etc. These represent - at least in theory – all moments in which students may be or maybe not given responsibility in and for the inquiry and thus the opportunity to "do RRI."

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

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

This main research question can be specified further into two:

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

The text is structured as follows. After detailing the general methodological strategy that we have followed during the study, we will dedicate ample space for presenting our ethnographic findings, trying to retain, as much as possible, the level of details and nuances as they appeared. This will be the empirical basis for a discussion in the third section that brings our observations in the classes to a higher level of abstraction hopefully clarifying the ambiguity that the term responsibility may happen to have. In the conclusions, we will briefly summarize our contribution and point to possible future developments.

METHODS

Participants

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

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

Procedure

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

The pre-interviews allowed an in-depth look at what the teachers meant by scientific inquiry and inquiry learning, as well as their familiarity with RRI. That provided the background for the observations that followed. The questions we asked in the pre-interview were, e.g., "How do you think

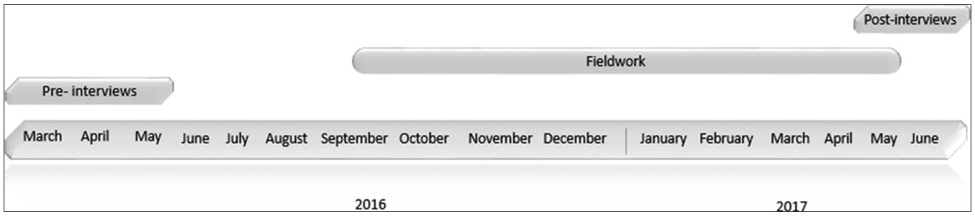

Figure 1: Timeline of the study

inquiry learning can be compared with the way in which scientists conduct their own inquiries?" "How do you usually bring up ethical/social issues in case an inquiry activity gives you the opportunity to do so?" The interviews were semi-structured and took place from March 2016 to May 2016. Only in one case the pre-fieldwork interview, observations in the class and post-fieldwork interview took place from March 2017 to May 2017. The length of the interviews varied from 20 to 90 min. We translated the selected extracts from the interviews into English and used them for the study.

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

Observations in the class focused specifically on:

1. Identification of the different inquiry phases and their function;
2. Transition from one phase to another;
3. Order of the phases;
4. Instructions given by the teacher at the beginning of the inquiry;
5. The main roles played by the teacher during each phase;
6. For what tasks the students were given responsibility in each phase.

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

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

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

Data Analysis

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

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

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

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

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

EXAMPLES FROM THE FIELD

Two Ideal Types: The Scripted Inquiry and the Open Inquiry

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

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

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

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

Before we proceed, it is important to mention that the inquiries observed did not substantially deviate from the inquiry model presented by Pedaste et al. (2015). Specifically, we have identified four phases: Orientation, Conceptualization, Investigation, and Conclusion. In presenting the examples from the field we will follow the same structure. It is worth noting, though, that in the model there is a fifth phase named discussion, which, according to Pedaste et al., spreads across the entire inquiry cycle. What we have observed is that discussions took place throughout the inquiry process and they were present in each phase. Therefore, to avoid being redundant, we decided to leave this phase out and concentrate on the remaining ones.

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

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

The Orientation Phase

Example 1

The first example that we present is closer to what we called the scripted approach to inquiry. The inquiry in question was carried out by 9th graders in collaboration with two biology teachers, Laila and Urmas, who decided to join forces for that occasion. The inquiry was aimed at investigating the effect of physical exercise on one's heart rate, and it started with one of the teachers showing a clip that was projected onto the screen situated in the classroom. The short clip provided a visual model of how the human cardiovascular system functions. The clip gave the teachers the chance to provide a short recapitulation of the main components of the heart, which was a topic that had been treated during a previous lesson. The clip also offered an introduction to the actual topic of the inquiry, for which the two teachers took full responsibility for. They also took responsibility for providing the kind of background information required to conduct the actual inquiry. No real discussion followed the projection of the clip. Since each and every student had a tablet at their disposal, the orientation phase ended with the teachers asking the students to download the template from the repository for use during the inquiry. The template contained all the prescribed inquiry phases the students had to go through during the lesson, and so it helped them be on track.

Example 2

A different pattern was shown by Liina – a class teacher of 2nd grade students. The aim of the inquiry was to measure the temperature of one's own body as well as that of different spots in and outside the classroom, e.g., in the schoolyard, at the window, and next to the radiators. The pattern that we observed sits somehow in between a scripted approach and a more open one. Like in the previous case, it was the teacher who decided what to inquire into, and she took the responsibility for introducing the topic. However, unlike the previous case, the kind of background information needed to carry out the inquiry was brought out through a discussion, which left room for students to have their own say. Specifically, as the teacher had previously asked the students to bring their own thermometer, she engaged the students in a discussion concerning what kind of thermometer the students had to use to measure the temperature in different places. While it was her leading the way, the students were fully engaged in discussing the possible options as well as trying to reach an agreement. As part of the orientation phase, the teacher showed the students how to write down the temperature values. Again, the teacher led the process here, but instead of providing the answers straightforwardly or expecting the right answer from the students, she invited them all to give their own opinion, which the students then tried to explicate. Regarding this specific example, in the post-fieldwork interview teacher Liina told us that she often asks students to bring their own equipment, because she feels that in this way they feel more included.

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

Example 3

This case was different from all others, first of all, because the inquiry activity spread across three 45-min lessons or meetings on 3 consecutive days. Second, as the lessons were part of an elective course that could be freely chosen by gymnasium students.

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

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

In the course of the first part of the lesson, the teacher informed the students about the plan for the next 2 days. The students had to work in groups to design and conduct an experiment for the 2nd day and present the results to the class on the third. He explicitly stated that students could freely choose a specific topic for the inquiry and use whatever they wanted – including their own imagination. Before wrapping up, he also added that in case they started panicking, they could do the work together with him.

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

The Conceptualization Phase

Example 1

In the previous section, we mentioned the inquiry concerning the cardiovascular system conducted together by teachers Laila and Urmas. The conceptualization phase, too, offers an example of a rather scripted type of approach. Similarly to the orientation phase, Laila and Urmas firmly led the process. Hence, after the topic was introduced by showing students a clip describing the main components of the heart, the teachers briefly described what they held in stock and then asked the students to guess their heart rate at rest and right after having a run through the entire school building. Students were supposed

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

scripted → open

Figure 2: Variations during the orientation phase

to write down their "hypothesis," which in this specific case was a guess to a specific question – their heart rate before and after the tour around the school. Students were not involved in making any meaningful decisions concerning the way in which to frame and/or conceptualize the main topic under investigation. The teacher took the responsibility for narrowing down the topic without engaging the students in the process. Here again the post-fieldwork interview helps provide context. Teacher Urmas expressed his concern in relation to the fact that eventually, students should provide the kind of answer that he expects. He also added that if every student came up with his/her own research question, the class would become simply unmanageable.

Example 2

A different example comes from another case, which is more open and less scripted. This was the case of teacher Hanna and her 7th grade students. The inquiry that they conducted was about reflex arc and reaction time. The topic was introduced by the teacher in the orientation phase. During this phase she made explicit several of the connections that the topic has with problems that students encounter in their everyday life. Chiefly, she talked about how alcohol or fatigue may have detrimental effects on one's reaction time and how bad that is in case a person is driving. While this part was led by the teacher, who, indeed, was making an effort to make the subject appealing to the students, in the conceptualization phase she involved the students directly in formulating the research question. While she herself told the students that reaction time can be faster or slower, she encouraged them to think of a research question based on the knowledge that they had previously acquired. To scaffold the process, she went to the blackboard, inviting the students to suggest a question that would follow the formula "how something influences something else." With the help of the teacher, the whole class eventually came up with a research question concerning how distracting factors influence our reaction time, which the teacher wrote down on the blackboard. Although the teacher gave several hints as to how to formulate the research question, the students were involved in the process of conceptualizing the main object of investigation, which, unlike the previous case, involved something more than having a guess as to what is going to happen. She was also open to the suggestions coming from the students and ready to include those as part of a brainstorming process. Interestingly, commenting on this specific case, teacher Hanna remarked in the post-fieldwork interview that her role is "to monitor and guide the process."

Example 3

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

The Investigation Phase

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

Example 1

Design of the experiment

The inquiry – carried out by 7th grade students in collaboration with teacher Ülle – aimed at the calculation of the volume of a cylinder. This was supposed to be done by immersing a cylinder in a small bowl containing water to measure how much the water level consequently rose. Before the experimentation subphase, the teacher went through the instructions provided in the worksheet that all students received at the beginning of the lesson. The teacher showed, one by one, every single piece of the equipment that the students were supposed to use, namely, a black cylinder not taller than 5cm and the bowl to fill with water. She also pointed to the sink right next to her desk where students would get water. In addition to that she gave the students a practical demonstration as to how to measure the diameter of the cylinder. She took extra care that students would write down the correct units next to the numbers.

Experimentation

During the actual experimentation students made decisions about the implementation of the plan previously devised by the teacher. The decisions concerned the execution of the steps required. Those included, for instance, measuring the diameter

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

scripted → open

Figure 3: Variations during the conceptualization phase

of the cylinder and pouring water into the bowl. While the teacher provided a demonstration of measuring the diameter, students had to skilfully put to use a ruler and set square. To fill the bowl with water, students – often in pairs – walked to the sink next to the teacher's desk and measured the amount of water poured in the bowl, making sure that it was the right amount. Some other decisions concerned teamwork and division of labor, e.g., who would pour water and who would measure its level in the bowl. The teacher left students freedom to decide whether to work in a group or not, and the students also decided how to assort themselves in the group. Only one student opted for carrying out the task alone.

Compilation and sharing of the results

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

Example 2

While the first case approximates, to a large extent, what we have called a "scripted" approach, we are now presenting a second case, which moves closer to the "open" type. The second case regarded another inquiry conducted by teacher Liina and her 2nd graders, whom we have already mentioned. The inquiry consisted in burying different items in the ground in September (right at the beginning of the school year) to see in May how much the different materials have degraded in the soil. Overall, the activity had the same structure as any inquiry. The investigation phase followed the orientation and conceptualization phases and was composed of the three subphases that we mentioned before.

Design of the experiment

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

Unlike in the previous case, matters concerning the "design" elements were not all settled at the beginning of the investigation phase. Hence, after the hole was dug and the items buried, the teacher asked how to remember the exact location of the hole in May. This was another important thing to decide on. Indeed, if the students could not locate the exact place, they would either waste a lot of time before digging out the items or the entire inquiry could be jeopardized. Here again a discussion followed. The first idea was to draw a map of the place. Since the hole was located a few meters from a metal post, some suggested wrapping an orange band around it. Some others counted the steps from the post to the hole. Interestingly, this last proposal triggered further questions, as then the students had to decide how to measure the steps.

Experimentation

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

Compilation and sharing of the results

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

Example 3

We now come to the third and last example, which is even closer to what we have termed the "open" type. We have already encountered teacher Leo and his students. As mentioned above, this was an elective biology course that 10th, 11th, and 12th grade students were free to choose. In this case, too, the investigation phase was characterized by three moments or subphases.

Design of the experiment

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

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

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

Experimentation

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

Compilation and sharing of the results

The results were shared by each group before the entire class in the third lesson. Every group collaboratively prepared a few slides in which they described in detail the kind of inquiry that they conducted – the research question, design of the experiment, independent variables that were chosen, etc. All inquiries were quantitative and the graphs displaying the data were commented on. During the presentations the teacher stood at the back of the room and listened attentively. He commented on each and every presentation, focusing mostly on technical aspects, such as the size of the sample (which in all cases were too small to allow generalizations) or the way in which the statistical analysis was done and the data visually presented. In general, he did not suggest any alternative way of doing the experiments, acting very much like a good reviewer – providing specific feedback on what the students did and showed. Figure 4 illustrates the variations occurred in the three cases presented and recapitulates the main differences.

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

scripted ⟶ open

Figure 4: Variations during the investigation phase

The Conclusion Phase

Example 1

Here again the first example concerns a more scripted type. The inquiry in question was performed by Laila, whom we have already met, and her class of 7th grade students. The orientation and conceptualization phases were part of a homework in which students were asked to design an experimental situation where CO_2 would form as a result of a chemical reaction. In the 45-min class the task was to perform, in groups, the experiment that students had prepared at home. All the groups opted for burning a match to demonstrate the formation of CO_2. Since the main aim of the inquiry was merely demonstrative, that is, to provide a demonstration of a specific effect, students were supposed to simply write down the result of the demonstration and were not asked to analyze what had happened during the experimentation any further. When the conclusion phase started, the teacher asked each group why the match had gone out and how the students knew that CO_2 had formed. Interestingly, in those cases in which the students did not get the expected result – that is, the one that the teacher expected – she simply told them that something practical went wrong during the experimentation. In the last part of the conclusion phase the teacher invited the students to explain the reason why CO_2 was formed by looking for the answer in their handbook.

Example 2

The second example comes from the inquiry lesson in which Liina and her 2nd grade students investigated how fast different items deteriorated when buried in the ground. As mentioned already, the first three phases took place right at the beginning of the school year, when a number of items were buried. The conclusion phase (and part of the investigation phase) took place in a lesson in May when the items were excavated. In the first part of the conclusion phase, the students extracted the items and it turned out that paper and cardboard were the most degraded materials. While the teacher was leading the discussion as to why it was so, the students actively participated in formulating a possible explanation. For example, an explanation that the students provided was that paper and cardboard were "made of nature." The way in which the teacher led the discussion was not meant to result in one single answer. Conversely, she waited for each and every student's opinion, valuing their effort to provide an answer rather than expecting the right one. Interestingly and unlike in other cases, in the conclusion phase the teacher engaged the students in a final reflection concerning what they had done, asking them what they enjoyed the most during the whole inquiry process that spanned across several months. The students took this last task very seriously and appeared very engaged in telling the teacher what they had liked. Here again the teacher welcomed all opinions, giving the clear message that there was no right answer and anyone could share his/her own view.

Like in the case of the orientation phase, we did not observe any example that was more open than the one described. It must be noted that on many occasions the conclusion phase was somehow shortened by the teacher simply because they ran out of time. It might be of interest, though, how the conclusion phase of the inquiry that involved teacher Leo and his students came to an end: As mentioned before, the investigation part ended with each group presenting the results of their inquiry. The teacher performed the role of a reviewer, providing specific feedback, mostly on the design of the experiment. After all groups had presented their results, the work done by the students provided the chance for the teacher to literally walk them through the key elements of scientific inquiry as well as provide a recapitulation of what the students had been involved in during the previous 2 days. He took care of naming and describing the elements so that the students could better understand why they did what they did. Those elements were the research problem and background information in the first phase; the hypothesis in the second; the experiment in the third; analysis and presentation in the fourth; and drawing the conclusions in the fifth and last part. He stressed, as he had done during the students' presentations, the crucial importance of sampling and the way in which results can be visually presented. The students listened attentively and one took a photo of the schema that the teacher delineated on the blackboard. However, no discussion followed. Figure 5 illustrates the variations occurred in the three cases presented and recapitulates the main differences.

DISCUSSION: TOWARD MAKING SENSE OF DOING RRI IN SCIENCE EDUCATION

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

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

scripted → open

Figure 5: Variations during the conceptualization phase

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

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

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

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

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

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

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

What we may claim is that when a pattern of inclusion based on what we called "answerability" is adopted, the chance of doing RRI is somehow de-potentiated, precisely because students are included as executors – they are responsible for simply executing the teacher's instructions. This becomes problematic, because in doing so students may fail to establish a deeper contact with the complexity and uncertainty of the inquiry process and thus – we add – with doing RRI. Wang and Wen (2010) remarked that direct instruction and teaching can have limitations, as it restricts "the development of students' process skills and abilities to make judgment." Shamsudin et al. (2014) observed that it is indeed easier for teachers "to assist students with a step-by-step guide to acquire content rather than letting them do the activity on their own and get confused."

Interestingly, in the light of what we have presented in the previous section, the departure from a scripted type of approach established (or contributed to establishing) a different pattern of inclusion and consequently a shift toward a different form of responsibility, which is central for making sense of how doing RRI can be interpreted. As we have shown, in less scripted inquiries the pattern of inclusion adopted by the teacher also changes the kind of decisions students are supposed to make and indeed the meaningfulness of their engagement as well. We see the progressive expansion of what we may call "the space of responsibility" for the students and consequently the possibility of doing RRI. The idea of a space expanding or shrinking – depending on the pattern of inclusion – helps us avoid seeing the whole issue in dichotomous terms, that is, "either or," but as something dynamically enacted and re-enacted.

Now, as the space of responsibility expands, students progressively cease to be the mere executors of an otherwise pre-determined script, for which they have to respond to the teacher. Conversely, they get more and more involved as agents of and in the inquiry, which is a central feature in RRI (Pandza and Ellwood, 2013).

As we have seen in less scripted inquiries, in the orientation phase students were given the chance to decide on the specific topic to investigate. Or, alternatively, they were actively involved in choosing the kind of equipment to use later in the experimentation or bringing their own, as it happened in the case of measuring the different temperatures. Regarding this specific example, we mentioned that teacher Liina stressed that asking to bring their own equipment is a way to make students feel more responsible, as the pieces of equipment are their own.

Moving on to the investigation phase, we have seen that this is the phase that offered ample room for students to decide. For example, we have seen that when teacher Liina let her 2nd grade students decide where to dig the hole to bury the items they chose, not only did the students get more engaged but they also had to face a number of unexpected problems they had to deal with, which is what we called "inquiries within the inquiry" to stress their unexpectedness. Discussions also had a different role. They spread across the entire inquiry and the teacher was open to the contributions that students could give without expecting the "right answer."

What is worth noting here is that the kind of responsibility that the students were given is of a different kind. While it would clearly be an overstatement to say that they ceased to be responsible to the teacher, the students progressively came to have more direct contact with the inquiry process during all its phases. This chiefly means that they were given the chance to start exploring the matter at hand for themselves and thus develop what Reed (1996) called primary experience. This – we claim – gives a different meaning to "doing RRI," as being responsible comes to denote more a type of engagement, which is potentially more meaningful precisely because the relationship with the inquiry is less mediated or less "processed" (Reed, 1996). Hence, we may argue that what we called "doing RRI" may come to designate a meaningful engagement with and in the inquiry, which, enabled by the teacher, allows the students to progressively take ownership and thus experience first-hand what it means to be responsible within an inquiry process that is – to some extent – open, and not predetermined in advance. In this process of taking ownership, in which the space of responsibility expands for students, the teacher may come to adopt different roles: For example, that of an initiator of a process, a challenger, a discussant or the one who invites students to inquiring.

CONCLUDING REMARKS AND FUTURE DIRECTIONS

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

The conclusion that we can derive is that the disambiguation of the term responsibility is fundamental to make sense of RRI in science education. When the meaning that the term acquires is closer to what we referred to as "answerability," as far as students are concerned, doing RRI is limited to becoming part of the inquiry process as executors, who simply respond to what the teacher expects them to do. Conversely, when the teacher places more emphasis on the inquiry as a more open-ended process including the students in it, the meaning of the term is closer to the idea of "meaningful engagement." This is an important distinction, because we may conclude that RRI in science education or simply "doing RRI" can be seen as the kind of meaningful engagement that is emerging when students are given the opportunity to contribute during the different inquiry phases for themselves. In this sense, RRI should not be viewed exclusively as an ethical add-on, but it is precisely the prerequisite for those ethical discussions to emerge.

From the teacher's point of view, though, including students in the inquiry process and thus leaving it open to their contributions means accepting a certain level of uncertainty and unpredictability, which may come in conflict with what the teacher thinks she/he is expected to do. Besides, as we have already mentioned, time was an issue that teachers stressed as a major factor hindering the possibility of adopting a different inclusive pattern.

More in general, we may say that the same ambiguity characterizing responsibility may apply to teachers themselves, who may adopt a different pattern of inclusion, precisely because they feel compelled to respond and therefore held accountable to parents, school directors, the national curriculum, and ultimately society (Qablan et al., 2009). This is something that inevitably takes us to a different type of path worth investigating in the future.

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

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APPENDIX 1

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

Scripted → Open