Introducing Responsible Research and Innovation (RRI) into the secondary school chemistry classroom

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Introducing Responsible Research and Innovation (RRI) into the Secondary School Chemistry Classroom: The Irresistible Project

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Abstract:

Responsible research and innovation (RRI) has become a core concept in some of the Horizon 2020 programs. In this chapter the concept of RRI is discussed according to the interpretation used within an EU-sponsored project, Irresistible. In the chapter we present several ways in which RRI can be introduced in secondary science education, coupled with contemporary research taking place in universities, as well as with recent innovations coming from industry. The discussed modules were designed in groups in which teachers work together with science researchers, educational researchers and people from science centers. The chapter focuses on the Israeli module that deals with the leading question: "Under what conditions would we agree to have perovskite-based photovoltaic cells installed on the windows of our school?" An innovative aspect of the pedagogical approach is the development of student-designed exhibits in which both the science content as well as the relevant RRI concepts are demonstrated for the general public. These exhibits have been very successful as a learning tool.

Key words: Secondary school education, Science education, Chemistry education, Formal learning, Informal learning, Student-designed exhibits, Responsible Research and Innovation, RRI, Contemporary science, Cutting edge research

Introduction

Responsible Research and Innovation (RRI) stands at the centre of several EU projects and represents a contemporary view of the connection between science and society. Previous 'techno-disasters' together with many facets of the current financial crisis have resulted in a loss of public trust in science and scientists across the world. The goal of RRI is to create a shared understanding of the appropriate behaviours of the European Commission, governments, business and NGOs (non-governmental organizations) which are central to building trust and confidence of the public and other stakeholders in safe and effective systems, process and products of innovation (Sutcliffe, 2011). The Irresistible project focuses on the design of science education activities that foster the involvement of students and the public in the process of responsible research and innovation. In the Irresistible activities, both formal and informal learning environments play an important role. The project raises awareness about RRI in two ways:

1) Increasing content knowledge about research by bringing topics of cutting- edge research into the program, and

2) Fostering a discussion among the students regarding RRI issues about the topics that are introduced.

In this chapter we describe the concept "Responsible Research and Innovation" (RRI), as well as the way it is introduced to students in secondary science education.

What is "Responsible Research and Innovation"?

Throughout the world, ideas about the interaction between science, innovation and society have become a subject of discussion. The UN, for example, has formulated millennium goals (The eight Millennium Development Goals (MDGs), 2015) for science. The OPCW has formulated the Hague Ethical guidelines (2015). Within the industrial society the idea of Responsible Care (2016) was written; and within the EU, this discussion has been going on for a while resulting in several framework programs.

Within the EU, the Framework programs about science and society have shifted in title from 'Science and Society' to 'Science in Society', indicating the change in perception within the EU about the role of science (Hoven, 2013). The concepts of Responsible Research and Innovation have become more and more important. In Hillary Sutcliff's report (Sutcliffe, 2011) she identifies six key dimensions in RRI.

In a later leaflet published by the EU in 2012 (EU, 2012) six key issues are identified: 1. Engagement; 2. Open Access; 3. Ethics; 4. Science Education; 5. Gender Equality; and 6. Governance. The six dimensions and their explanations are presented in Table 1. Several other definitions for RRI were provided and further contributed to the RRI concept.

Van Hoven (van Hoven, 2013) indicates:

"RRI refers to ways of proceeding in Research and Innovation that allow those who initiate and are involved in these processes at an early stage (A) to obtain relevant knowledge on the consequences of the outcomes of their actions and on the range of options open to them and (B) to effectively evaluate both outcomes and options in terms of ethical values (including, but not limited to well-being, justice, equality, privacy, autonomy, safety, security, sustainability, accountability, democracy and efficiency) and (C) to use these considerations (under A and B) as functional requirements for design and development of new research, products and services."

Schomberg (von Schomberg, 2013) defines RRI as follows:

"Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."

Both Schomberg and van Hoven focus on the interaction between society, on one hand, and and research and innovation, on the other. They demonstrate the importance of this interaction in order for research and innovations to succeed in society. A common example is genetically modified food, which has not been accepted in Europe. Especially the steps formulated by van Hoven are not common as yet even though governments have started to formulate policies on this subject. In the Netherlands, for example, a new report was published indicating the view of the Dutch government on the future development of policies regarding scientific research, which are solidly based on these RRI concepts (Wetenschapsvise 2025, 2014).

Within the Irresistible project we decided to use the six key issues (presented in Table 1) as a starting point in the design of the activities within the project. They provide a more concrete set of issues that can be incorporated within educational activities. The underlining idea, that both research and innovation should be closely linked with society and with societal needs is the background of the use of these six dimensions. Using the six key issues gave the project a solid base to discuss how the cutting-edge research could be introduced to the students. In order to be able to work according the six RRI dimensions, we developed a more descriptive explanation of them, as presented in Table 1.

1. Engagement The first key to RRI is the engagement of all societal actors - researchers, industry, policymakers and civil society – and their joint participation in the research and innovation process, in accordance with the value of inclusiveness, as reflected in the Charter of Fundamental Rights of the European Union. A sound framework for excellence in research and innovation entails that the societal challenges are framed on the basis of widely representative social, economic and ethical concerns and common principles. Moreover, mutual learning and agreed practices are needed to develop joint solutions to societal problems and opportunities, and to pre-empt possible public value failures of future innovation.
2. Gender Equality Engagement means that all actors – including women and men – are on board. The under-representation of women must be addressed. Research institutions, in particular their human resources management, need to be modernized. The gender dimension must be integrated in research and innovation content.
3. Science Education Europe must not only increase its number of researchers, it also needs to enhance the current education process to better equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the research and innovation process. There is an urgent need to boost the interest of children and youth in maths, science and technology, so they can become the researchers of tomorrow, and contribute to a science-literate society. Creative thinking calls for science education as a means to make change happen.
4. Open Access In order to be responsible, research and innovation must be both transparent and accessible. This means giving free online access to the results of publicly-funded research (publications and data). This will boost innovation and further increase the use of scientific results by all societal actors.
5. Ethics European society is based on shared values. In order to adequately respond to societal challenges, research and innovation must respect fundamental rights and the highest ethical standards. Beyond the mandatory legal aspects, this aims to ensure increased

Table 1. The 6 Dimensions of RRI used in the Irresistible project

In order to get a clear idea about the use of these six dimensions of RRI and to share the same understanding within the project's partners, a workshop was organized by the Weizmann's partners, in which the coordinators in each participating country participated. During that workshop, two case studies were discussed in which the six dimensions could be applied.

The first case study that was discussed was the use of asbestos. The group discussed whether applying of RRI policies could have changed the use of asbestos in society and prevent the catastrophe caused by its use. Main question to be answered during the workshop was how the problems with asbestos could have been avoided, using RRI-based policies.

For the second case study, nanosocks were introduced. (see Figure 1.)

Figure 1. Nanosocks

Nanosocks (2016) contain nano silver particles that inhibit bacterial growth and thus prevent smelly socks. This contemporary innovation was used for a discussion about the six dimensions of RRI and the way they should be applied to nanosocks. Through this discussion, participants developed an idea about the way the six dimensions could be applied to an innovation like nanosocks. This experience was taken by the participants to be used during the development of educational material.

The Development of the Educational Material

Within the project, a Community of Learners (CoL) was formed in each country as the group to develop its educational material ((Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010). Both in the Netherlands in the development of 'Nieuwe Scheikunde'(Apotheker, 2008) as well as in Germany in 'Chemie in Kontext'(Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007) these communities have been used and are still used in the development of new teaching and learning materials.

In the Irresistible project, each CoL included experts from science research, educational research, science centres, teachers, and (when possible) a representative from industry. Together the CoL members worked on the development of the new educational material. The pedagogy of inquiry was chosen to lead the new teaching and learning materials. We chose to use the 5E method developed by Roger Bybee (Bybee, Taylor, Gardner, Van Scotter, Carlson, Westbrook, & Landes, 2006) as a framework for the modules to be developed. The Irresistible group decided to expand the 5E model with a step called Exchange, in which the students exchange their results and build an exhibition. In Table 3, the resulting 6E model is represented.

Phase	Description	Techniques used
Engage	Students are motivated to engage in the subject of the module. Both formal and informal learning activities areplanned.	TV broadcast, visit to science centre, video introduction, apps, lecture by researcher. Students may gather information using smartphones to make videos, photos or other data that can be shared via social media (e.g., a Facebook group).
Explore	Studentsformulatequestions plan explorations, and implement their plans.	A Web platform is used for gathering data and for comparing and sharing results.
Explain	Students gain knowledge through data collection and scaffolding. The main concepts are explained.	The teachers and the students will scaffold the content knowledge on the web platform.
Elaborate	The attention shifts to elaborating on the concepts by asking RRI-questions. Students confront researchers with challenges to be answered by the scientists.	Using the web platform, students match questions and answers by scientists.
Exchange	Students design and construct an exhibit, to be displayed in the science centre in the partners' local group. Posters or other presentation modes may also be used.	Contest for best exhibits, which will participate in an exhibit on a European scale, hosted by one of the partners.
Evaluate	Students are tested on their content and RRI-relatedknowledge. The students themselves determine by an interview/ discussion with the researchers what they learned from the project.	Online tests and surveys can be used for testing and for discussion with the researchers.

Table 3. The 6E Model for Inquiry-Based Learning Used in the Irresistible Project Results

Thirteen different modules dealing with variety of cutting-edge science topics were developed by the Irresistible partners. Each partner chose a research topic currently being investigated in their university and cooperated with the researcher to obtain contemporary scientific information. Table 4 presents the topics of the modules developed by each partner.

Country	Title of the Module	Cutting-Edge Research Topic
Finland	Atmosphere and Climate change	Atmosphere and Climate change
Germany	Oceanography and climate change	Offshore wind energy
	Plastic, Bane of the Oceans	Plastic waste in oceans
Greece	Nanoscience applications	Several nano-applications like the lotus effect
Israel	The RRI of Perovskite-based photovoltaic cells	Perovskite solar cells
Italy (Bologna)	Nanotechnology for information by exploiting light/ matter interaction	Luminescent nanosensors
Italy (Palermo)	Energy sources	Graetzel cells
Netherlands	Carbohydrates in breast milk	Specific oligo-saccharides
Poland	The catalytic properties of nanomaterials	Role of nano particles as catalyst
Portugal	Geo-engineering and climate control	Geo-engineering
	Evaluatingearth health through polar regions	Polar ecosystems
Romania	Solar energy and specific nanomaterial	Graetzel cells
Turkey	Nanotechnology applications in health sciences	Nanomaterials used in health issues

Table 4. Produced modules, with science content.

All the modules included the 6E framework. The teachers in each CoL tried out their module in their own classrooms. The modules have been adapted using teachers' experiences in the classroom. A further improvement of the module was conducted by international exchange of the modules between the Irresistible partners. Each module was tested in a different country and the feedback obtained was used to improve it. The modules are available through the Irresistible (2016) website.

Implementation of RRI

The implementation of RRI in the modules has been done in different ways. In the modules of Israel, Turkey and Germany the students are given a specific role. Incorporated in the role-play are the different RRI aspects. In the Turkish module the students are given the role of an advisor. A hospital is asking them whether or not the hospital should introduce towels sheets and other products made of textile treated with nano silver particles that have antibacterial properties. They then investigate the properties of cotton treated with silver nanoparticles and finally, by discussing the consequences of washing textile-containing silver nanoparticles, they highlight the key aspects of RRI and come up with a recommendation.

In the German module, a game has been developed in which the students play different roles and in this way learn about offshore wind energy. Since the Fujiyama disasters in Japan, Germany decided to invest heavily in wind energy.

The students' main question in the Israeli module is "Under what conditions, if any, would we agree to have perovskite-based photovoltaic cells installed on the windows of our school?" The module includes the following components: (1) a pre-visit RRI unit for the students, given in their classroom before the visit, (2) a visit to the Weizmann Institute's outdoor science museum (The Garden of Science) on the topic of alternative energy (Figure 2), (3) a high-quality "special news broadcast" which frames the guiding question for the students, (4) background articles for the students, (5) a lecture on alternative energy and photovoltaic cells, (6) a student experiment on photovoltaic cells and (Figure 3), (7) an activity to help students design exhibits, based on the guiding question, (8) a discussion with Weizmann Institute graduate students about their research, from an RRI perspective, and (8) a post-visit session on building the exhibits, back in the classroom, leading to a presentation of the exhibits to other students.

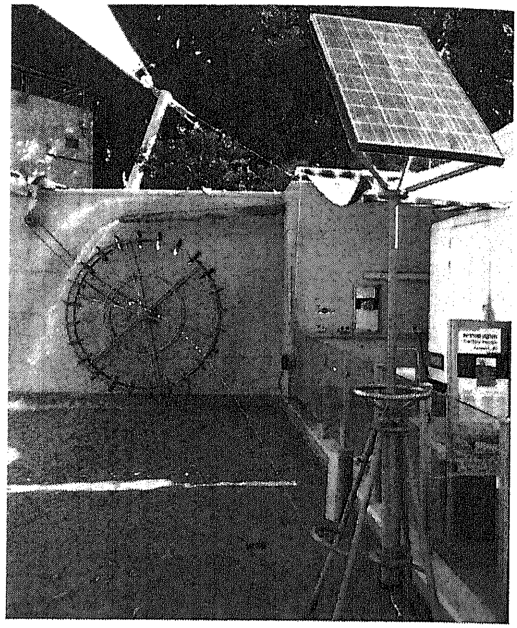

Figure 2: One of the exhibits in the Clore Garden of Science, demonstrating the working principle of solar panels.

Figure 3: A solar cell built during the students' visit in the Weizmann Institute of Science, to deepen their knowledge of the working principle of solar cells.

The six areas of RRI are addressed by the module in a number of ways. First, before the students arrive at the Weizmann Institute, they receive a 3-hour lesson on RRI (Blonder, Zemler,

& Rosenfeld 2016) which is based on the history of the use of lead in different industries. The students are challenged to think of ways in which the use of lead in these industries could have been prevented and they are guided to learn about the six keys of RRI. Second, the students are engaged in thinking about RRI during their visit to the Weizmann Institute, in terms of the module's guiding question regarding the use of perovskite-based photovoltaic cells. Third, the students design an exhibition that includes RRI dimensions of the perovskite-based photovoltaic cells innovation. Finally, toward the end of their visit, the students meet Weizmann Institute graduate students, who describe their research and invite students to ask them questions regarding this research as it relates to RRI.

In other modules, the RRI dimensions were introduced during the 'Elaborate' step of the 6E framework as a separate part of the module. Students were then asked to apply the RRI dimensions to the science content they studied in the first part of the module, and to present their findings in various ways.

Figure 4. Students debating about propositions, in the Netherland.

In some cases a debate was organized around specific propositions such as, "A company has the right to market their products all over the world," taken from the module about milk formula, as shown in Figure 4.

In all cases, the students were asked to design and construct an exhibit demonstrating the dimensions of RRI and focusing on the the relevant science content.. These exhibits were taken to the local science centre involved in the project and displayed there. Students were guided in their exhibit-designing efforts by the science centre staff.

In Germany, a system for the exhibits was developed using a cupboard from 'Ikea' (Figure 5). The cupboard was designed by the students to illustrate the issues involved. In this case, the module is about the differences between human milk and cow milk.

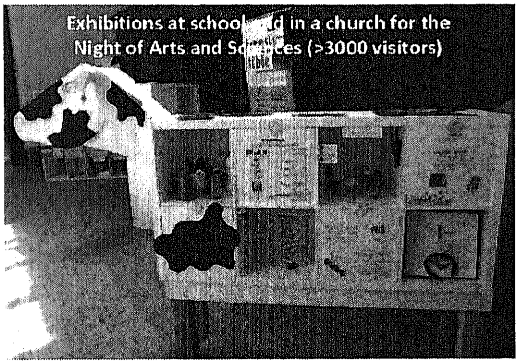

Figure 5. Use of an Ikea cupboard as the base for an exhibit (The Netherland exhibition).

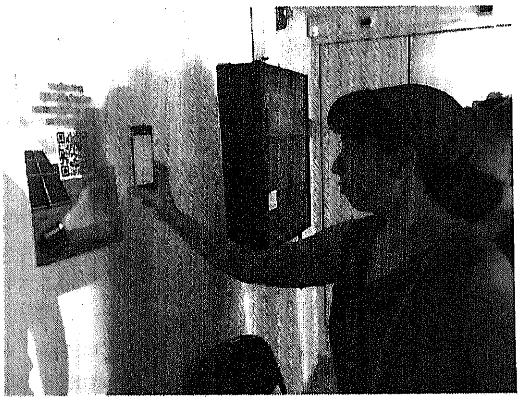

Figure 6. Use of QR codes to create interactive exhibits (from the Israeli exhibition).

In other cases, interactive exhibitions were created by applying technologies such as QR codes and on-line quizzes, as demonstrated in Figure 6 by one of the exhibitions that was developed in Israel. Students are very creative in designing exhibits. Through careful guidance by the experts from the various science centres, exhibitions are made that can actually be used in these science centres.

Conclusions and Recommendations:

Looking at the modules and more specifically at the exhibits that have been produced by the students, it becomes clear that the Irresistible modules are able to introduce cutting-edge science research into the secondary school classroom. In most cases, this approach fits in with the curriculum in a country, and in other cases the material is considered extra-curricular enrichment.

What also becomes clear is that the students are very able to link the RRI dimensions to the science they have been studying. In Israel RRI has become more or less a verb: 'Let's do RRI on this issue' (Blonder, Zemler, & Rosenfeld, 2016). The exhibits are an important factor in the modules in bringing together the science and RRI. Designing the exhibits forces the students to think about the issues and come up with ways to demonstrate to society the RRI dimensions of the research and/ or innovation.

In most modules, all six dimensions were addressed. During a presentation of the modules in a meeting of the project in Bologna, it became clear that the gender dimension as well as the science education dimension were not always easy to implement in the modules. These two dimensions were found to have high societal importance and therefore the awareness of the students to their importance is essential. However, it is not trivial to use them as a lens to examine a scientific research or an innovational development.

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