The project Irresisitible: Introducing Responsible Research and Innovation into the Secondary School Classroom

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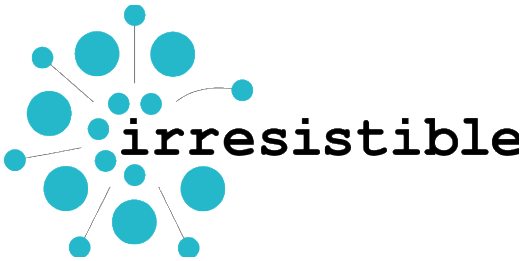

Abstract:

Responsible research and innovation has become a core concept in some of the Horizon2020 programs. In this article the concept of RRI is discussed and the interpretation used within the project 'Irresistible' is introduced.. In the article several ways in which RRI can be introduced in secondary education are discussed, coupled to contemporary research taking place in universities as well as recent innovations coming from industry.

The discussed modules are designed in groups in which teachers work together with science researchers, educational researchers and people from science centers. Part of the educational material is the development of exhibits in which both the science content as well as the RRI concepts related to the science are demonstrated for the general public. These exhibits have been very successful as a learning tool.

Key words: secondary school education, science education, formal learning, informal learning, exhibits, Responsible Research and Innovation

Introduction.

The project 'Irresistible' is the result of a proposal that was accepted within the FP-7 program of the EU under number 612367. The proposal was made in response to call SIS.2013.2.2.1. (*Workprogramme 2013 capacities part 5, science in society*.2012):

Area 5.2.2.1. Supporting formal and informal science education in schools as well as through science centres and museums and other relevant means.

SiS.2013.2.2.1-1: Raising youth awareness to Responsible Research and Innovation through Inquiry Based Science Education

Within the project IRRESISTIBLE activities are designed that foster the involvement of students and the public in the process of responsible research and innovation. The project raises awareness about RRI in two ways:

- Increasing content knowledge about research by bringing topics of cutting edge research into the program
- Fostering a discussion among the students regarding RRI issues about the topics that are introduced.

In these activities both formal and informal learning environments play an important role.

In this article the description of the concept' Responsible Research an Innovation' as well as the way it is introduced to students in secondary education is the central topic.

The concept of 'Responsible Research and Innovation'

Throughout the world ideas about the interaction between science and innovation with societal issues has become a subject of discussion. The UN for example has formulated millennium goals (http://www.un.org/millenniumgoals/) for science. The OPCW has formulated the 'The Hague Ethical guidelines' (https://www.opcw.org/special-sections/science-technology/the-hague-ethical-guidelines/) with a direct link to the Chemical Weapons Convention'. Within the industrial society the idea of 'responsible care' (http://www.cefic.org/Responsible-Care/) 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)). Within the EU the concepts of Responsible Research and Innovation have become more and more important. In Hillary Sutcliff’s report (Sutcliffe, 2011) she identifies six key concepts in RRI(see table 1):

Table 1. Aspects of RRI as identified by Sutcliff and RRI leaflet

Sutcliff	**RRI leaflet**
The deliberate focus of research and the products of innovation to achieve a social or environmental benefit.	Engagement
The consistent, ongoing involvement of society, from beginning to end of the innovation process,	Gender equality
Involvement of the public & non-governmental groups, who themselves are mindful of the public benefit.	Science education
Assessing and effectively prioritizing social, ethical and environmental impacts, risks and opportunities, both now and in the future, alongside the technical and commercial.	Ethics
Where oversight mechanisms are better able to anticipate and manage problems and opportunities and which are also able to adapt and respond quickly to changing knowledge and circumstances.	Open acces
Where openness and transparency are an integral component of the research and innovation process.	governance

In a later leaflet published by the EU in 2012 (http://ec.europa.eu/research/science-society/document_library/pdf_06/responsible-research-and-innovation-leaflet_en.pdf) six key issues are identified (see table 1).

Van Hoven ((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:
Definition: 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 and research and innovation. They demonstrate how important this interaction in order for innovations to succeed in society. An 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 project we decided to use the six key issues from the leaflet 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 gives the project a solid base to discuss how the research that is being introduced to the students. In table 2 the six dimensions of RRI are explained a bit further.

Table 2. **The 6 Dimensions of RRI (text taken from leaflet) used in the project**

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 –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 societal relevance and acceptability of research and innovation outcomes. Ethics should not be perceived as a constraint to research and innovation, but rather as a way of ensuring high quality results.
6. Governance Policymakers also have a responsibility to prevent harmful or unethical developments in research and innovation. Through this key we will develop harmonious models for Responsible Research and Innovation that integrate public engagement, gender equality, science education, open access and ethics.

In order to get a clear idea about the use of these six dimensions of RRI in the project a workshop was organized in which the coordinators in each participating country participated. During that workshop two issues were discussed in which the six dimensions could be applied.

The first issue that was discussed was the use of asbestos. The group discussed whether the use of RRI policies would have changed the use of asbestos in society. Main question to be answered during the workshop was how the problems with asbestos could have been avoided, using RRI-policies.

For the second issue nano socks were introduced. (see figure 1.)

Figure 1. nanosocks

Nano socks (https://www.nanosilver.eu/Tema/Why-Nanosilver/Magical-Socks-Nanosilver-with-Silver-Nanoparticles) contain nano silver particles that inhibit bacterial growth and thus prevent smelly socks. This innovation was used for a discussion about the six dimensions of RRI and the way they could be applied to nano socks. Through this discussion participants got an idea about the way the six dimensions could be applied to an innovation like nano socks. This experience was taken by the participants to be used during the development of educational material.

The development of the material

Within the project Community of Learners have been formed to develop educational materials ((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 material.

Within the Community of Learners experts from science research, educational research, science centres and teachers are brought together. When possible someone from industry was included as well. Together they worked on the development of new material.

Inquiry based science education as well as context oriented chemistry education has been developed and worked on during the past 10 years(Kennedy, 2014)(Pilot & Bulte, 2006)(Apotheker 2008). In this project the partners chose to use the 5 E method developed by Roger Bybee (Bybee, Powell, & Towbridge, 2007) as a framework for the modules to be developed. This 5 E model has been extended to a 7 E model by Arthur Eisencraft (Eisenkraft, 2003), in which he decided to expand the first and last step in the model. The Irresistible group decided to expand the 5 E model with a step called Exchange, in which the students exchange their results. In table 3, the 6 E model is represented.

Table 3. The extended 5 E Model.

Phase	Description	Techniques used
Engage	In the engage phase students are getting interested in the subject of the module. Both formal and informal learning activities will be planned	Applications, visit to science centre, video introduction, lecture by researcher. Students may gather information using smartphones to make videos, photos or other data that can be shared in a Facebook group for example.
Explore	In the explore phase students start formulating questions,	A Web platform is used for gathering data and comparing and sharing results

Explain	In the explanation phase knowledge is gained, data collected and scaffolded	The teachers and the students will scaffold the content knowledge on the web platform.
Elaborate	In the elaboration phase the attention shifts to RRI-questions. Students will confront researchers with challenges to be answered by the scientists	Using the web platform students will match questions and answers by scientists.
Exchange	One of the assignments will be the design of an exhibit, which will 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	In the evaluation phase the students are tested on their content knowledge. 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

Results

In Table 4 the titles of the modules developed by each partner are given.

Table 4. Produced modules, with science content.

Country	**Title**	**Research subject**
1 Portugal	Geo-engineering and climate control	Geo-engineering
	Evaluate earth health through polar regions	Polar eco systems
2 Finland	Atmosphere and Climate change	

3 Turkey	Nanotechnology applications in health sciences	Nanomaterials used in health issues
4 Poland	The catalytic properties of nanomaterials	Role of nano particles as catalyst
5 Netherlands	Carbohydrates in breastmilk	Specific carbohydrates
6 Romania	Solar energy and specific nanomaterial	Graetzel celss
7 Italy (Bologna)	Nanotechnology for solar energy	Graetzel Cells
	Nanotechnology for information by exploiting light/ matter interaction	Luminescent nanosensors
Palermo	Energy sources	Graetzel cells
8 Israel	The RRI of Perovskite based photovoltaic Cells	Perocskite solar cells
9 Germany	Oceanography and climate change	Off shore wind energy
	Plastic, Bane of the Oceans	Plastic waste in oceans
10 Greece	Nanoscience applications	Several nano-applications like the lotus effect

All modules that were developed have included the 6E framework. The teachers in the CoL have tried out all modules in their own classrooms. The modules have been adapted using their experiences in the classroom.

The modules are available through the Irresistible website: http://www.irresistible-project.eu/index.php/nl/ .

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 etc treated with nano silver particles. 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 an advice.

The main question in the Israeli module is whether the windows in the school should be replaced with Perskovite solar cells

figure 2 . example of perovskite solar cells used in windows(http://news.sciencemag.org/node/112358)

In the German module a game has been developed in which the students paly using a different role and that way learn about off shore wind energy. Since the Fujiyama disasters in Japan, Germany decided to invest heavily in wind energy.

In other modules the RRI dimensions were introduced during the 'Elaborate' step of the framework as a separate chapter. (figure 3.)

4— Elaborate

Responsible Research and Innovation (RRI)

'Society becomes more involved'

Many people think of science and innovation as activities that are carried out by smart people, far away at universities and companies. Sometimes, it seems as if scientific research does not properly match with what is important to society and that 'ordinary people' have no influence on it. The European Union has created the term 'Responsible Research and Innovation' (RRI) to achieve that people can more easily converse with scientists and the business world. In this way, society becomes more involved in scientific research and innovation.

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This is what Responsible Research and Innovation is about: people working on scientific discoveries and innovations, must do so in a responsible way.

RRI has six components:

1. Engagement: researchers, industry, policy makers, and citizens have to collaborate in the research and innovation process. In this way, social, economic, and ethical interests of all groups can be included to find a joint solution for societal problems.

The European Union, the United Nations, and other governmental institutions have identified a number of 'Grand Challenges' of modern day society that science could answer. These challenges are worldwide problems such as clean drinking water, proper food production, poverty, hunger, and climate change, as well as aspects that focus more on Western society, such as healthy aging, Internet safety, and sustainable transportation. Good education and reducing child mortality are also on these lists.

In the Netherlands, the government has established the 'Science Vision 2025' in November 2014. This vision states the challenges for Dutch society. These are: quality of life, circular economy, resilient society, building blocks of life, complexity: coping with unpredictability and big data. For society, it's important that exactly these problems are solved by means of scientific research and innovations, by engaged researchers.

2. Gender equality: men and women must be equally involved in research and innovation; the full potential of the population must be used. In 2011, over half of the people graduating from university in the Netherlands were women, but less than 15% of professors is female (Monitor Vrouwelijke Hoogleraren, 2012). People mainly think of men when talking about professors (do a Google Images search for 'scientist').

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Figure 3. Introduction of RRI in a chapter of a module.

Students were then asked to apply the RRI dimensions to the science content they studied in the first part of the module. Presentation of the results of these studies were various in nature.

Figure 4. Students debating about propositions

In some cases a debate was organized around specific propositions. An example is: 'a company has the right to market their products all over the world' taken from the module about formula milk.

In all cases the students were asked to make an exhibit demonstrating the dimensions of RRI focused on the science content they learned about. These exhibits were taken to the science centre involved in the project and displayed there. 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.

In other cases cartoons were used (figure 6). In figure 7 an overview of the exhibition in Greece shown.

Students are very creative in designing exhibits. By careful guidance by the experts from the science centres exhibitions are made that can actually be used within the science centres.

figure 5. Use of an Ikea cupboard as base for an exhibit

Figure 6. Cartoons made to illustrate RRI -issues

Figure 7. Overview of exhibition in Greece

Students are able to use the advice they have received about exhibits in novative ways. In Italy for example a table football game was adapted to demonstrate principles of RRI. (figure 8)

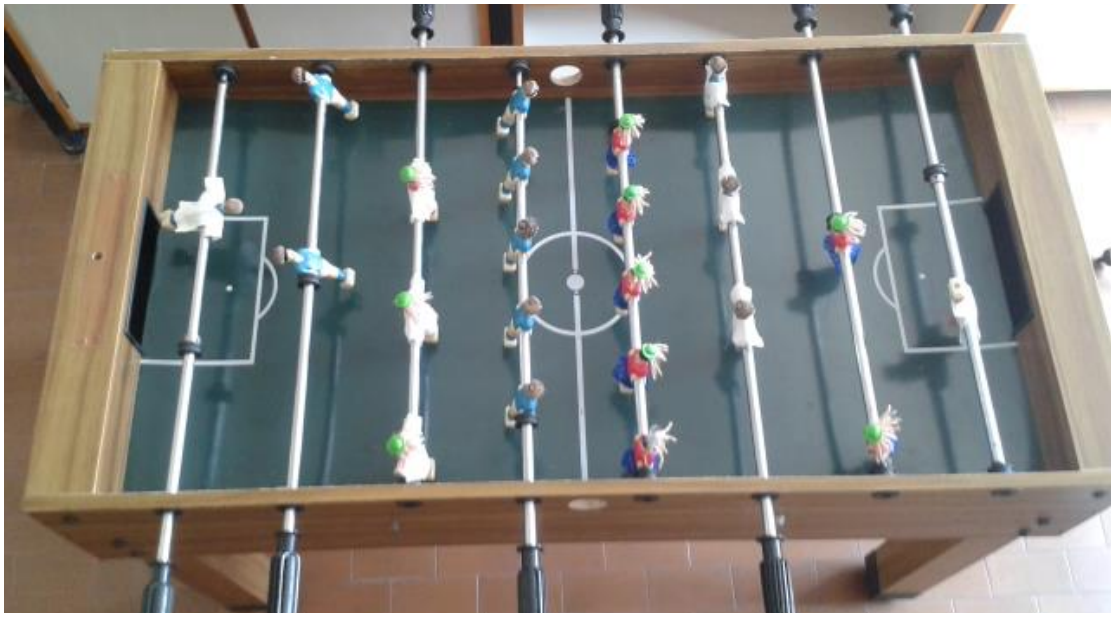

Figure 8. Table football game adapted in Italy with male and female players.

Table 5. Rules of the soccer game and their link to RRI

RRI dimensions	Rules to demonstrate dimension
Engagement	Red ball. Play the citizens only (Red) Public opinion often puts a brake on scientific progress.
Gender equality	Yellow ball Keep your eyes closed while playing! Why use sight when you've got hearing too?
Science education	Question mark ball! Science has the answer to many questions...
Ethics	X-ball, Science discoveries are unexpected. Change team but not the score.
Open acces	Green ball Interlock your arms with your mate Collaboration is necessary for playing,

	experimenting and working. Collaborate if you want to win.
governance	Blue ball Twist your arms Science is regulated by government.

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 on the one hand to introduce cutting edge science research into the secondary school classroom. In most cases this fits in with the curriculum in a country in other cases the material is extra curricular.

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 it has become more or less a verb: *'let's RRI this issue'* .

The exhibits are an important factor in the modules in bringing together the science and the 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 the presentations of the modules during 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.

Acknowledgements

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 612367.

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