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Published in:
Israel Journal of Chemistry

DOI:
[10.1002/ijch.201800081](https://doi.org/10.1002/ijch.201800081)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2019

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Apotheker, J. (2019). The Irresistible Use of Contexts in Chemistry Education. *Israel Journal of Chemistry*, 59(6-7), 608-617. <https://doi.org/10.1002/ijch.201800081>

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The Irresistible Use of Contexts in Chemistry Education

Jan Apotheker*[a]

Abstract: In an introduction the position of chemistry education over the past twenty five years is discussed. The relative low interest of students is discussed as well as some ways that were formulated to counteract this low interest and raise the number of students electing to study science and more in particular chemistry. Context oriented chemistry is one of these solutions, in which a specific context related to everyday life is chosen as a starting point to learn about chemistry. An example from an FP7 project, called Irresistible is presented, to demonstrate the use of contexts. In this project several other aspects were introduced as well. One of

them was the introduction of current science research in the classroom. The idea is that students get a better understanding of science at the university when confronted with (results) of recent research. A second aspect is the introduction of the concept of 'Responsible Research and Innovation'. This concept formulated by the EU, discusses the link between scientific research and society, and specifically the way science can play a role in solving problems society is confronted with as formulated for example by the sustainable development goals of the UN.

Keywords: secondary education • chemistry education • responsible research and innovation • teacher training • context oriented education

1. Introduction

Chemistry education in secondary schools has gone through a number of changes in the past twenty years. Things were not going well with chemistry education. The appreciation for chemistry dwindled, the number of students electing to study chemistry at the university dropped to alarming numbers.

In 'Science Education Now'^[1] an OECD report is quoted from which it becomes clear that the number of students electing a Science and Technology course dwindled by more than 40 % in some cases between 1994 and 2003. In 2010 the ROSE (Relevance of Science Education Report)^[2] project reported about the relevance of science (and chemistry) education in schools for boys and girls.

It became clear that science education was not appreciated very much by large groups of students. Even though the attitude of students towards the role and benefits of science appears to be positive. Some statements quoted from the ROSE project:

- Science and Technology make our lives healthier, easier and more comfortable
- New technologies will make work more interesting
- The benefits of science are greater than the harmful effects that it could have

These statements have been given to students that scored them around 3.7 on a Likert scale^[3] of 1 through 5, indicating a high level of agreement. If you look at scores relating to science in school the results are completely different.

School science is

- Less interesting than other subjects
- Has not opened my eyes for new and exciting jobs
- Has not shown me the importance of Science and Technology for our way of living

Low interest in subjects like:

- Detergents, soaps and how they work
- Chemicals their properties and how they react

For boys only subjects like:

- How petrol and diesel engines work
- Explosive chemicals
- The possibility of life outside earth seem to have some interest.

It is clear that the chemistry curriculum at that time (around 1990) was not very attractive. There was little or no link with society. There were a number of main subject students were expected to learn, that had little or nothing to do with research at universities. Furthermore the main subjects like equilibrium, acid base theory and redox reactions, taught in secondary schools did not really clarify the position of chemistry as a molecular science, a science focusing on the study and control of molecular processes. Other factors contributed as well:^[4]

- Teacher domination
- Curriculum content
- Perfectionism
- Competitive assessment
- Traditional teaching methods
- Poor environment

were reported as being factors with a negative impact on the quality of chemistry education.

At the same time the need for scientists and more specifically chemists, was made more explicit by public bodies

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like the UN and the EU. The EU formulated the Lund declaration (European Union, 2015) which specified that Europe needs to work together to deal with a number of grand societal challenges like climate change, energy and water supply, public health, ageing society changes in world economy. This declaration has had major influence on programs like Horizon2020. Around the same time the UN formulated its sustainable development goals (United Nations, 2016). These development goals are more concrete, than the goals formulated by the EU, and give focus to scientific development that is needed to reach these goals.

In order to be able to work on these sustainable development goals, society needs to have enough scientists. Education in general and more specific chemistry education has an important role in forming these scientists.^[7]

This has set the scene for extensive work from several institutions to try and find ways to improve the situation of chemistry education. Most specifically trying to improve education in such a way that science becomes more attractive for students. Since early 2000 developments have started to work on improving science education.

One of the first originated from the University of York, and was called 'twenty first century science'.^[8] Another was developed together with the American Chemical Society, and was called 'Chemistry in the Community'.^[9] These materials all had contexts from which students learned chemistry. The link with the 'real' world was paramount in introducing new concepts. Another concept based on the idea of 'need to know' was introduced as well. Only those concepts that are needed to understand a specific 'real life' situation are introduced. In 'Chemistry in Context'^[10] a first year college textbook, meant for students that were interested in chemistry, this was worked out even further, with subjects like 'the air we breathe', 'climate change', 'brewing and chewing'.

Rocard et al., (2007) published on behalf of the European Union a report about the situation in science education. In this report a number of suggestions were made.

One of the suggestions was to make a change in science teaching pedagogy, from more traditional methods of teaching to inquiry-based methods of teaching. This involves a change in role between teachers and students, in which students play a much more active role in education. They need to do be active in the inquiry process. In traditional teaching using lectures the role of students is much more passive.

Another important conclusion of the report was that teachers are considered to be key players in the renewal of science education. The development of networks of chemistry teachers in a region for professional development was deemed an important form of teacher training.

^[11] reported a year later again with a number of recommendations about science education. They emphasized the relation between science education and the material world, more than being a foundational education for future engineers and scientists. Innovative curricula, focusing on low student motivation should be stimulated. The use of contexts in order to understand science better, were mentioned specifically. In this report the role of science teachers as major stakeholders in the development of high quality science education is emphasized as well.

This has led to several programs within the Framework Programs of the EU,^[12] notably in the FP7 program^[13] as well as within Horizon2020 (European Commission, 2017). In these programs the introduction and development of Inquiry Based Science Education was an important factor.

These programs have stimulated the development of alternative programs. In a special issue of the International Journal of Science Education^[15] context oriented science education was highlighted, as a way to improve the appreciation of students for science.

In several countries developments started to introduce a new context oriented chemistry curriculum (Apotheker, 2008; Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007).

Some of these developments have led to new curricula (Apotheker et al., 2010) or the formulation of new standards.^[19]

2. The Project Irresistible

The project Irresistible was one of the last FP7-projects that was funded by the EU (Apotheker et al., 2017). It had a double focus. It intended to

- Increase content knowledge about research by bringing topics of cutting edge research into the program
- Foster a discussion among the students regarding Responsible Research and Innovation issues about the topics that are introduced.

In order to bridge the gap between secondary school and higher education it was deemed important to introduce cutting edge science in a form that secondary school students could

Until his retirement in December 2016 Jan Apotheker was the lecturer for methodology of chemistry teaching in the department for teacher training. He coached students during their in-service training, and during their research. In the faculty of mathematics and natural sciences he was a lecturer in the institute for the development of education. Between 2002 and 2012 he was part of the group that developed a new chemistry curriculum for the Netherlands, which was implemented in September 2013. From 2013 until November 2016 he coordinated the FP7 project 61367 'Irresistible'. In which 14 partners worked together in a project on teacher training and the development of new educational material.

Table 1. Research areas used in the project Irresistible.

Country	Title	Research area
1. Portugal	Geo-engineering and climate control	Geo-engineering
	Evaluate earth health through polar regions	Polar eco systems
2. Finland	Atmosphere and climate change	Climate change
3. Turkey	Nano for health	Nanomaterials used in health issues
4. Poland	The catalytic properties of nano materials	Role of nanoparticles as catalyst
5. Netherlands	Carbohydrates in breast milk	Role of specific carbohydrates
6. Romania	Solar energy and specific nanomaterial	Grätzel cells
7. Italy (Bologna)	Nanotechnology for solar energy	Grätzel Cells
	Nanotechnology for information by exploiting light/matter interaction	Luminescent nanosensors
Palermo	Energy sources	Grätzel cells
8. Israel	The RRI of perovskite based photovoltaic cells	Perovskite 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

understand. In Table 1 titles and research areas are indicated that were chosen as a base for educational material to be used in secondary and primary schools.

Educational researchers, working together with research groups at the university, chose the research areas. In so-called community of learners, researchers worked together with secondary school teachers to develop new educational materials. The educational researcher coached the community of learners. Together they developed a first version of the material, which was tried out in the schools of the secondary school teachers. After a revision of the material the participating countries exchanged the materials for further evaluation. After this second round the material was reviewed once more. This revised material is now available on the website of the project: <http://www.irresistible-project.eu/index.php/en/>. The material can be used instead of a chapter in the textbook normally used by teachers.

3. Responsible Research and Innovation

Responsible Research and Innovation is a concept that has been coined by the EU, linking chemistry and more in general science education to societal issues.^[21]

Table 2. Six main concepts of Responsible Research and Innovation.

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 mathematics, science and technology, so they can become the researchers of tomorrow, and contribute to a scientifically 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

Six main concepts have been identified to describe the broader concept of RRI. These six concepts are given in Table 2.^[22,23]

From this table it becomes more or less clear what is meant with RRI.

van Hoven (Hoven, 2013, page 12) 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.”

In the educational modules that were developed in this project these ideas were implemented as well.

4. Example

A concrete example of the way these issues are implemented is the module ‘Carbohydrates in breastmilk’. (Apotheker & Teuling, 2017). The cover of the module is shown in Figure 1.

The contents of the module are:

1. **Engage** – Secrets of Breast Milk
“Why don’t babies just drink milk from the supermarket?”
2. **Explore** – Unravelling the Secrets
“Do you have the Guts?”
3. **Explain** – Gathering Knowledge
 - 3.1 Biology
 - 3.2 (Bio)chemistry of milk
 - 3.3 Process chemistry

Figure 1. Cover of ‘Carbohydrates in Breastmilk’.

4. **Elaborate** – RRI in research about breast milk and formula

5. **Exchange** – Making an Exhibition
Sharing Knowledge

6. **Evaluate**

The chapter titles reflect the methodology of inquiry based learning used in this module. It is called the 5 E method,^[26] developed by Roger Bybee.

The first chapter of the module starts by posing the question:

‘Why don’t baby’s drink milk from the supermarket?’

Humans are (also) mammals

Human beings, apes, cats, dogs, cows, goats; they all belong to the class of Mammalia: mammals. The common characteristics of mammals is that they ‘nurse’ their offspring, that is, feed them by means of breast milk. All mammals produce milk after giving birth that has the ideal composition to help their offspring grow optimally. Goat’s milk is made for goats, cow’s milk is made for calves, and human milk has its own special composition, that optimally help babies to develop.

It introduces the differences between these types of milk, focusing on content of proteins, fats, and carbohydrates. Human Milk Oligosaccharides are specifically mentioned. These form the base of the research of this module. A research group at the University of Groningen identified certain HMOS, that play an important role in the development of the bacterial flora in babies (see Figure 2).^[27] They developed ideas in which these HMOS could supplement formula food for babies.^[28] This idea was further developed in close cooperation with a company that produces formula milk for babies (see Figure 3). They developed a process to produce oligogalacto saccharides, that have the same role as HMOS, and can be added as a supplement to formula milk.

After the introduction and discussion of the research indicated above in chapter 2, the module goes on to give background to the research, so that it is better understandable. In chapter 3 it is linked to content that is normally discussed in secondary school biology as well as chemistry. For biology, the way components of milk are digested in the digestive system. A difference is made between the digestive system of babies and that of adults. The importance of liquid feeding in the first three months is explained, as well as some problems like lactose intolerance as well as cow milk allergy, which is linked to protein size. Again here a link is made to societal issues. Details about the world wide spread of lactose intolerance are discussed and possible causes are discussed as well (see Figure 4).

In a second biology chapter microbiology is introduced, Metagenomics is introduced as the way in which information about the types of gut bacteria is obtained (see Figure 5).

The development of gutbacteria is shown in Figure 6.

Based on these observations the difference between certain types of bacteria are shown.

It is important to note that while discussing general knowledge, that students should learn anyway, the module

Figure 2. Possible effects of human milk oligosaccharides (HMOs). Source: adapted from Saulnier et al, 2009.

Figure 3. Different types of formula (source: bol.com).

constantly refers to the general theme and context of the module, explaining different aspects.

The same goes for the chemistry chapters, that deal with the biochemistry of fats, proteins and carbohydrates. This normal chemistry content for upper secondary chemistry courses, but is linked here to the content of breast milk. Process industry is discussed based on the production of galacto oligo saccharides, see Figure 7 and 8.

Special in this module is that both chapters from biology as well as chemistry are discussed.

In the next section (Elaborate) the knowledge gained is reviewed and linked to aspects of Responsible Research and Innovation. The advertisements for formula milk are strictly

regulated since the Nestlé campaign in 1977 (Nestle boycott) by the World Health Organization 1981.

The problems with the addition of melamine in China in 2009 are discussed, as well as aspects of emancipation related to breast feeding by working women.

Students are expected to form their own opinion about these issues, finding arguments in the things they learned in the previous chapter.

In the Exchange chapter which is special for the project Irresistible students are asked to build an exhibit, that can be used in a science museum. It should explain and demonstrate what they have learned in the module both the science aspects as well as the RRI-aspects. This group assignment in which the whole class is involved demonstrates clearly what the students have learned about the different aspects of breastfeeding. In Figure 9 an example of an exhibit is shown that was used in a science fair in Groningen, which was visited by more than 3000 people.

In the final stage of the module during the evaluation, the students write an exam covering the science content they have learned.

5. Results of the Project

The project Irresistible was evaluated using several instruments (Vocht, Laherto,& Parchmann, 2016). In Table 3 these instruments are described. Some of these are focused on the organization of the project, others were focused on the effect.

Detailed information about the results, was published within the project and in some articles.^[29–31] Below some interesting results are discussed.

Figure 4. Percentage of the population with lactose intolerance in various parts of the world. Source: Chemische Feitelijkheden Melk.

Table 3. Instruments used in the evaluation of the project Irresistible.

Instrument	For whom?	When?	Analysis	Focus
Online questionnaire, incl. • States of Concern • IBSE • Exhibit Design • Social aspects of science education	All CoL members: • teachers • scientists • science education experts • museum staff	2 (optionally 3) times during both rounds of CoLs: * pre: during early CoL meetings * (intermediate: after the initial design of the module) * post: after testing with students	Descriptive results (means) for the first round; statistical analyses (SPSS) for the second round	Development of modules
RRI questionnaire for CoL members	All CoL members: • teachers • scientists • science education experts • museum staff (+ 10 teachers outside the CoL in the first round)	Once during round 1 Twice during round 2 (pre: during early CoL meetings; post: during the last meeting)	Descriptive results (means) for the first round; statistical analyses (SPSS) for the second round	Development of teachers
Criteria for modules checklist	One representative of each partner (country)	At the end of the module development (round 1) and during module implementation (round 2)	Qualitative content analysis	Quality of the modules
Student questionnaires • RRI • Exhibit design • Social aspects of science education	School students participating in the module (separate questionnaires for primary/secondary school)	Twice (pre-post) during module implementation in both rounds	Statistical analyses (SPSS)	Development of the students
Case study on exhibition development, incl. • interview with 1 teacher • focus group interview with students	A teacher and a group of students	At the end of exhibition development in both rounds (and possibly using observations and interviews during the exhibit development phase, for those who are interested in the systematic analysis option)	Simple analysis & formative report Optionally: Systematic analysis leading to a research report	Exhibition as assessment tool
Project evaluation questionnaire	One representative of each partner (country)	In 2016	Simple statistical	Total project

Through the answers to the questionnaires teachers that participated in the project were classified according to their profiles. About a third of the teachers was qualified as ‘Enthusiasts’ with very little negative concerns and a lot of

Figure 5. The technique of metagenomics applied to feces (source carbohydrates in breastmilk).

Figure 6. Development in gut bacteria, (source 'carbohydrates in breastmilk').

Table 4. Concerns of experts and teachers in the project (averages based on a Lickert scale $-2 = \text{disagree}$, $-1 = \text{slightly disagree}$, $1 = \text{slightly agree}$ & $2 = \text{agree}$).

Do you have concerns about	Experts	Teachers	difference
Limited knowledge	0,2	0,5	-0,3
Abilities	0,6	0,3	0,3
Practice	0,2	-0,3	0,5
Time	0,8	1,2	-0,4
Preoccupied with other things	0,4	0,8	-0,4
Need to revise work	-0,1	-0,6	0,5
Students	0,4	0,1	0,3
Revision of approach	0,6	0,4	0,2

Figure 7. Production of GOS, using galactosidase (source 'carbohydrates in breastmilk').

Figure 8. Production process of formula milk (source 'carbohydrates in breastmilk').

Figure 9. Example of an exhibit about carbohydrates in breast milk (authors photograph).

Table 5. Teachers and students attitudes towards RRI and its dimensions. Measured by a questionnaire, (Lickertscale 1–5).

RRI dimension	Teachers		Students	
	pre	post	pre	post
Engagement	3,9	4,3	3,9	4,0
Gender equality	3,9	4,5	3,7	3,9
Science Education	4,1	4,5	3,9	4,2
Open Access	4,1	4,4	3,7	3,8
Ethics	3,9	4,3	3,7	3,8
Governance	3,7	4,1	3,6	3,7
General RRI	3,9	4,4	3,8	3,9

positive interests.^[32] Two other clusters were the 'practical concerns' cluster and the 'un-confident' cluster. These teachers focus mainly on practical concerns, such as getting information and managing the teaching. They are also enthusiastic in their positive attitudes. The un-confident-group needed help in acquiring skills to teach about RRI. When comparing the pre and post-test, teachers' negative concerns reduced significantly, while their positive concerns remained roughly the same. The conclusion was that the teachers who participated in the project were seen as forerunners in educational innovations.

Teachers worked together with scientific experts in the Community of Learners, that worked together on the design of the modules. The experts and teachers indicated they had slightly different concerns about certain items (see Table 4).

The attitudes of teachers and students towards RRI and its six dimensions was also assessed through a Lickert based questionnaire, with answers ranging from 1 to 5. As was expected from the profiles of the teachers attitudes towards RRI were already very positive, but improved during the project. The results are given in Table 5.

Students had a very positive attitude towards RRI, but their attitude did not change significantly after they had worked through a module.

The module described above has been carried out successfully in Israel, Greece and the Netherlands. Evaluation was carried out as part of the project, through questionnaires, both among students as well as teachers. These results were published as evaluation reports of the project,^[33] which can be found on the projects website (www.irresistible-project.eu). Both teachers and students are positive about the material. They feel they have learned enough science, but also have learned a lot of the different aspects relating to the use of breast milk compared to formula milk.

An overview of teachers reactions was published in 2017.^[32] An overview of students responses was published a year earlier.^[34] One of the main problems mentioned by teachers is the time needed to go through the module.^[30] Most countries have a fairly well defined curriculum and only limited time in school to go through the curriculum. This is not only problem for the particular module discussed but is also the case for the other modules. Teachers need to invest time in order to use the modules and adapt to their own needs and situation. Nevertheless, the modules are successful in raising awareness about RRI.^[34]

6. Conclusion

The use of this type of contexts helps raising the awareness of the role of science in society, linking current research to aspects and subjects, students can relate to directly. This is highly motivating for the students and the teachers.

Contexts can of course also be used in higher education. Both societal problems as well as real time research problems can be used in that respect. Using authentic problems will help students understand better why they need to learn certain material.

The concept of RRI is definitely a subject that can be introduced as well in higher education. Specifically asking questions about the need for a certain innovation, the consequences of the use of certain innovations in the past can be used as examples (use of polyethylene for shopping bags, as well as the use CFK's as propellant).

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Manuscript received: July 1, 2018
Version of record online: October 12, 2018