Context-based chemistry learning

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Chapter 2

CONTEXT-BASED CHEMISTRY LEARNING: THE RELEVANCE OF CHEMISTRY FOR CITIZENSHIP AND RESPONSIBLE RESEARCH AND INNOVATION

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ABSTRACT

Chemistry is related to almost every material, question, and topic. Chemical reactions take place in every living organism, in the environment, and in the industrial production of all the different products we use. Still it has a negative connotation for many laypersons. Educational links between contexts and the multi-perspective facets of chemistry aim to develop a better foundation for citizenship and responsible research and innovation (RRI). This chapter will give reasons for and explore such approaches of context-based learning in chemistry.

Keywords: chemistry in context, citizenship, responsible research and innovation, decision-making

INTRODUCTION

Chemistry is everywhere. Chemical reactions take place in every living organism, in the environment, and in the industrial production of all the different products we use. Still it has a negative connotation for many laypersons; they associate chemistry and chemical substances with risks and disadvantages for their health and the environment, rather than positive effects for their daily-life and societal developments. Educational links between contexts and the

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multi-perspective facets of chemistry aim to develop scientific literacy among students and laypersons - a foundation for citizenship and Responsible Research and Innovation (RRI).

Such approaches have been developed and implemented in chemistry curricula and syllabi in many countries around the world; among the first the Dutch *PLON* (Wierstra, 1984), the British *Salters Chemistry* (Bennett & Lubben, 2006), different US-American approaches (Schwartz, 2006; Ware & Tinnesand, 2005) and already building up on those the German *Chemie im Kontext* (Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007). Context-Based Learning (CBL) in science relates to educational goals like Scientific Literacy (Bybee, 1997), Science-Technology-Society (STS) (Aikenhead, 2006), Socio-Scientific Issues (SSI) (Sadler, 2009), or lately Responsible Research and Innovation (RRI) (von Schomberg, 2013). Even though these approaches differ from each other with regard to their main emphases, they all follow the paradigm of linking contexts relevant for societal developments and individual experiences to basic chemistry knowledge, and research topics and processes. Contexts are applied as an introduction as well as a backbone to structure the learning processes, they are not just 'wrappings' for chemistry content that disappear after the first opening.

In this chapter, we will further explore the relevance of chemistry and develop arguments for an application of context-based chemistry learning from an educational, an empirical and a political point of view.

CONTEXT-BASED CHEMISTRY: EDUCATION FOR DIFFERENT GOALS AND PERSPECTIVES

Education for Scientific Literacy, Life-Long Learning and Professional Applications: The Relevance of Chemistry

The relevance of chemistry is ubiquity, due to its omnipresence in everybody's life. This, however, does not mean that everyone has to and wants to understand all underlying principles of the objects and processes we use. Stuckey, Hofstein, Mamlok-Naaman, and Eilks (2013) have described three dimensions of relevance: the individual, the societal and the vocational dimension (see also Eilks & Hofstein, 2015). CBL approaches, like those mentioned above, choose contexts and order them according to the students' interests at certain age groups in similar ways. They usually start with contexts (topics, questions, activities) close to the students' own daily-life, like food, moving towards societal issues, like plastic waste or energy consumption, and highlighting career perspectives in further school years. Even within one context different activities can point out different perspectives of relevance, as Prins, Bulte, and Pilot (2016), and also Broman and Parchmann (2014) have discussed. A context on food can be approached from a personal perspective, investigating contents of certain drinks, for example, with regard to health issues. It can also lead to societal discussions like conditions of food production. From a professional perspective, analytical methods and careers in different industries form another approach.

On a meta-level, the relevance of chemistry can be discussed with two perspectives also taken as a structuring principle in the last PISA studies: knowledge *of* science (e.g., chemistry) and knowledge *about* science (e.g., chemistry). The latter points out the need to understand how science arguments are built and how scientific evidence is generated to become able to evaluate information and take decisions based (also) on science arguments. With regard to chemistry, an understanding of analytical procedures and values, including measurement errors and standard deviation is one important aspect, leading back to the basic principle of Paracelsus: All things are poison and nothing without poison; the dosage alone makes that a thing is no poison.

While knowledge *about* chemistry is usually knowledge about scientific procedures in general, knowledge *of* chemistry is specifically related to the basic concepts (Nentwig et al., 2007) or big ideas (Talanquer, 2016). The most important concept of chemistry is the explanation of every chemical process and property based on atoms and their interaction. Atoms form structures like molecules and ionic lattices, those form bulks and substances, with different properties. Atoms are not destroyed in chemical reactions; they form new structures and substances. Chemical reactions and technical applications therefore lay the foundation for all processes and products with regard to matter in the world. The better the combination of atoms can be predicted and led, both with regard to matter and energy, the better the quality of the syntheses that can be carried out with regard to health, environmental and thereby sustainability issues. A basic understanding of such chemical principles can form a solid basis of understanding for many highly important societal issues like:

- Waste can never be 'destroyed', atoms will persist no matter what procedure is undertaken. It can only be processed towards something useful or stored. Therefore, recycling measures and the production of products with further perspectives of use are crucial.
- The combustion of fuels will always produce fumes, again because of the persistence of atoms. The composition of fumes depends on the composition of the fuel, thereby chemists can work on fuels better for the environment, not without any harm though.
- Functional materials are based on chemical properties and processes. There is no detergent, no medical drug, no water proof clothing without chemicals, even though this is often promised in advertisements. Products from nature also contain substances, a fatty acid is a fatty acid no matter whether it is produced by an organism or in a lab. Again, the importance, with regard to sustainability issues, is the way a substance is produced, how much 'waste' (atoms not needed in a product) is produced and how much energy is consumed. Both are topics of chemical research, as well as the waste that is produced by the products themselves. Dealing with waste is one of the major issues for societies and better solutions, including chemical reactions, are needed soon.

The important role of chemistry has recently been pointed out by the Seville International Chemistry Declaration 2016 of the European Associations of Chemical and Molecular Sciences (EuCheMS available at: http://www.euchems.eu/seville-international-chemistry-declaration-2016). The arguments given here certainly require adequate education for all future citizens.

How can we support (future) citizens to better understand this relevance? The major goals of school chemistry are, like for other school subjects, to enable students to become a reflective citizen, to develop a foundation for future learning and professional education and to develop personal interests, abilities, self-concepts, etc. While the latter needs to be realized by and for each individual, the first three goals can be classified in a more general sense.

The educational goals Scientific Literacy (e.g., Bybee, 1997) and citizenship incorporate not only knowledge *of* but also knowledge *about* science, as already explored. Students and citizens need to understand how scientific arguments are developed, which questions can be investigated and answered by scientific studies and how results are evaluated with regard to general conclusions but also limitations. Chemistry is related to almost every material question and topic, but chemistry alone cannot decide among norms and cultural habits. Fuels, for example, can be analyzed by chemists to investigate parameters like energy balances or the composition of emissions. They can be optimized by industrial chemists with regard to balances of usable components and waste or energetic processes. However, decisions for or against a particular fuel are not only taken based on arguments from chemistry. The production of one fuel might have side-costs for the production of another fuel, considering workforce and employment or public costs. A product might be usable as a fuel or as food, like biofuels produced from plants. And it is hard to decide which technology will have greater potentials for a sustainable future, as many side-effects on the one hand or new technological opportunities on the other often have not been predictable in the past. Students should be educated in a way that allows them to develop basic knowledge, conceptual understanding and competences, but also to continuously apply and evaluate their knowledge with regard to decision-making processes like the one on fuels. Citizenship builds on chemical knowledge and competences; this should be highlighted already during chemistry classes and beyond.

A foundation for life-long learning and any further professional education require basic knowledge and an understanding of different fields of applications, among them professional fields, related activities and required competences. Chemists work in many different areas, such as research or industrial chemists. Other fields like administration, teachers, medical assistants and many more are less explicitly in focus when thinking of chemists. And even those that everybody has in mind are often associated with stereotypes. For instance, the chemist is often associated with a male in a white lab coat, working alone in his lab. Research has shown that such stereotypes not only exist but might even hinder young people, especially girls, from becoming a chemist (Lederman, 2007; Wentorf, Höffler, & Parchmann, 2015). Context-based learning in school and beyond aim to improve this situation (Braund & Reiss, 2006; Parchmann, Broman, Busker, & Rudnik, 2015). The comparison between stereotype beliefs and the own prototype perception influences the choice of professional learning and future engagement, next to self-efficacy beliefs, experiences of competence and other variables (Wentorf et al., 2015). With regard to the latter, and therefore to life-long learning, a current trend in science education investigates and describes these called learning progressions (Duschl, Maeng, & Sezen, 2011; Sevian & Talanquer, 2014) as structures of effective curricula for the development of knowledge and competence. CBL approaches need to consider these in addition to other variables, as explored in the next section.

Framework and Approaches of Context-Based Learning in Chemistry

Frameworks for CBL need to connect contexts and content, through activities aiming to develop competences, in many ways. The design of context-based material and units needs to raise the students' interest, activate the students' pre-knowledge, guide them through scientific investigations, offer situations for the application of the newly developed knowledge and for connecting this new knowledge to general structures like basic concepts (see Figure 1).

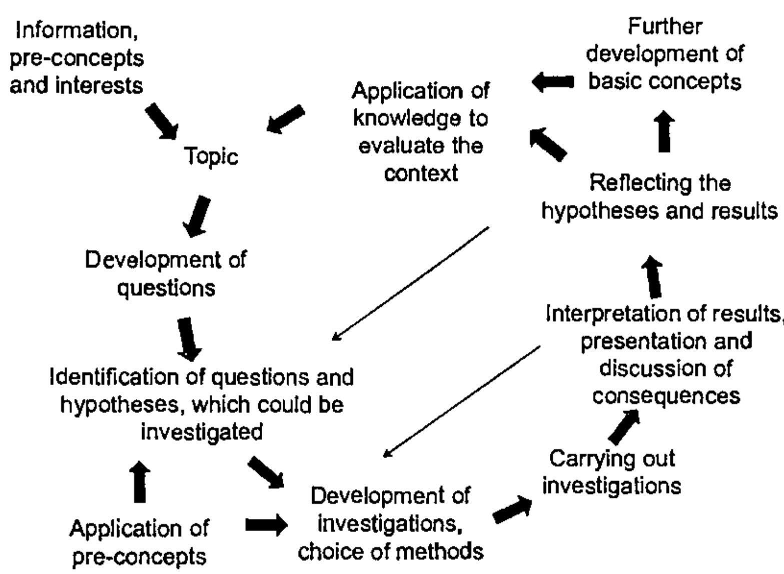

Figure 1. The development cycle of a context-based unit.

Curriculum development therefore needs to consider characteristics of contexts as well as structures of conceptual understanding, bringing both in a suitable order over the time of school chemistry (see Figure 2).

For the development of an understanding of redox-reactions, for example, school normally begins with reactions of metals and oxygen. These reactions take place in corrosion processes and elsewhere. Corrosion, or the prevention of corrosion, is highly important for our society; it is also known to students, e.g., from their bikes. However, with regard to learning, the process of corrosion is more complicated than other reactions between a metal and oxygen, like blowing metal powder in a candle flame. Those, on the other hand, do not have a direct relation to the students' experiences. Old bulbs are used to offer a suitable context, but bulbs are forbidden in the EU nowadays. This example points out that combining contexts and steps of learning is not a simple challenge. The different approaches mentioned in the introduction have solved this challenge and developed material and units for lower and upper secondary education. Table 1 gives an overview about a possible combination of contexts for lower secondary education.

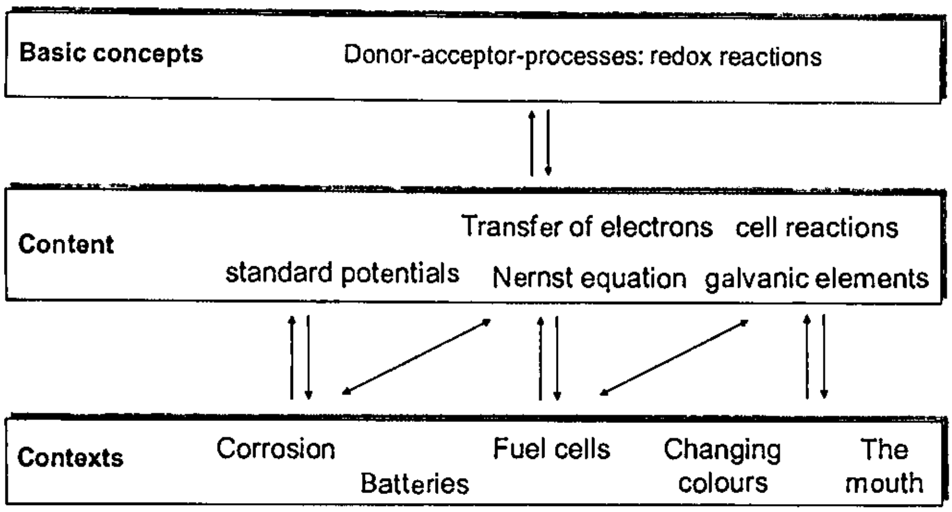

Figure 2. Three levels of knowledge in *Chemie im Kontext.*

Table 1. Exemplary units of *Chemie im Kontext*

Context	Guiding Questions	Content and Activities
The Taster	How do we know what's in our food? How do tasters work nowadays? How do chemists explain the invisible?	The barriers of our senses Chemical identifications First introduction to models
Fuels for mobility - and side-effects!	Why cannot chemists develop a fuel without emissions? From fuels to carbon dioxide - and back? Alternatives free of CO_2 Can metals burn?	Analyses of fuels and combustions Cycles of reaction: Conservation of atoms Elements in the Periodic Table
Water - not common at all!	Water - a *charmelion* of properties How to chemists explain (changes of) properties? Water and life - what makes water so important?	Experiments with water Models of molecules The formulae H_2O and its predictive potential Solubility: structure-property-relations

Another characteristic of CBL is the interaction between students, teachers, the context and the content. *Chemie im Kontext*, for example, describes four phases of the learning process (Parchmann et al., 2006), as show in Figure 3.

The teacher designs the first Phase of Contact to allow the students to apply their knowledge and make connections between the context and their interests. The second phase acts as an advanced organizer. Here, the students and the teacher develop and structure guiding questions leading to further investigations. The third phase is the main phase and enables students' research projects, group work and other active learning activities of the students, scaffold by the teacher. The fourth phase needs to be driven by the teacher, as experience of many years has shown. The abstraction of concepts and knowledge that should be transferred after each unit is challenging and requires guidance as well as tasks for training and application.

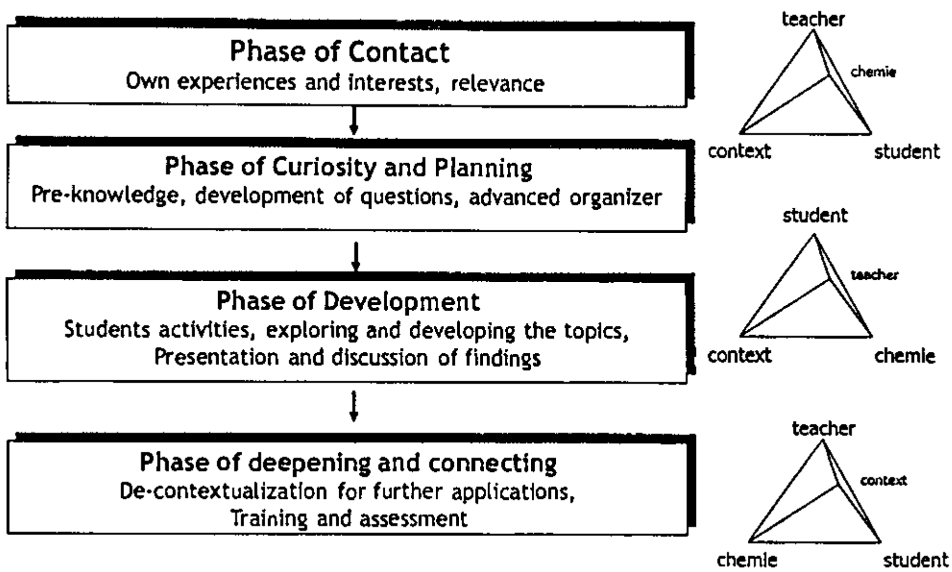

Figure 3. Phases of Chemie im Kontext and related interactions between the students, the teacher, the context and the chemical content (note: tetrahedron figures taken from Jan Apotheker, cited in Parchmann et al., 2015).

Context-based learning does not end in school. Many out-of-school learning environments are lately taken into consideration as enrichment especially for more interested and talented students. They offer authentic insights into research or projects of societal engagement like Citizen Science (e.g., www.safe-ocean.org). Approaches of CBL outside the school building (Braund & Reiss, 2006; Falk & Storksdieck, 2010) are even older than school learning, but seem to be recovered again nowadays. They can build bridges to professional contexts by presenting up-to-date research areas and topics, real methods and equipment, and last but not least, persons working as professional chemists. Student labs are one trend of development for CBL outside the classroom; videos are another format. Both can be and should be connected to school to ensure continuous learning as a successful integration of school and out-of-school contexts.

CONTEXT-BASED CHEMISTRY: EMPIRICAL FOUNDATION

Context-Based Learning for Motivation and Interest

One main goal of context-based learning is to raise interest and motivation for chemistry and chemistry learning at school. This goal derives from theories and models of motivation and interest, like the well-known Self-Determination Theory, by Deci and Ryan (2000). Elements of those theories are taken into consideration by CBL frameworks like *Chemie im Kontext* (Nentwig et al., 2007), aiming to raise interest and motivation by pointing out the relevance of a context and the necessary knowledge and competence (relevance), by enabling students to experience their own abilities (perception of competence), to choose their own field of interest (autonomy), by working with peers (social embeddedness) and/or by becoming able to present outcomes to family and friends (social embeddedness and perception of competence).

Studies investigating motivation and interest for CBL approaches have clearly shown effects of this assumption. In comparison to other approaches, CBL does raise interest and motivation overall (Bennett, Lubben & Hogarth, 2007; Nentwig et al., 2007). Looking more carefully at the results, differences can also be found. Not every context is of equal interest (Broman & Simon, 2015; Sjøberg & Schreiner, 2012), and not every unit works in every class (Parchmann et al., 2006). The perception of relevance can be different between students, the teachers and the curriculum developers. Is a context 'Fuels for today and tomorrow' relevant to a 16-year old, just because he or she will drive a car in the future and just because the topic is highly relevant for a society? What makes a context relevant? Is it the content or the activities carried out within a context on the content? (Broman & Parchmann, 2014; Prins et al., 2016). Fuels can be investigated scientifically, but they can also be discussed with different stakeholders. CBL approaches aim to consider different perspectives of interest and engagement, linked to different aspects of relevance. However, further research is needed to specifically understand what makes a context motivating and which aspects might even hinder CBL from being successful.

Context-Based Learning for Understanding and Applicable Knowledge

With regard to knowledge, conceptual understanding and competence, the outcomes of research are diverse. While some studies report better cognitive learning outcomes from CBL, others did not find any differences (Bennett et al., 2007; Broman & Parchmann, 2014; King & Ritchie, 2013).

One reason is again the lack of understanding of what exactly a context initiates within a learning process. Qualitative studies currently investigate learning processes in addition to learning outcomes. They analyze the students thinking step by step to follow their development of argumentation, starting from a context and applying different aspects and levels of knowledge (Broman, Bernholt & Parchmann, 2015). One result of these studies is the need for further differentiation of a 'context': Do we mean a field of application, a content area, an activity (Blankenburg, Höffler & Parchmann, 2016; Broman & Parchmann, 2014; Bulte, Westbroek, de Jong, & Pilot, 2006)? Studies might not be comparable already due to different meaning of the term 'context' in CBL. The so called 'chemical triangle', enlarged by a fourth element 'context' or 'human element' (Mahaffy, 2006; Parchmann et al., 2015) offers a structure for a more differentiated focus on a context and its relation to chemistry (see Figure 4).

A context can be defined as a situation in which a person (the 'human element') interacts with chemistry in a certain way, usually different in a daily-life, a societal or a professional situation (Broman & Parchmann, 2014). If you look for a new coat, the functionality will only be one argument, next to the price, the look among others. The chemistry applied might be the reflection of terms like 'water-proof' or of risks like influences on health by the material. From a professional point of view, the specific explanation and further development of functional material is of high interest, related with analytical and synthetical activities and the development and use of models on structure-property-relations. These are two examples showing how a context can be designed very differently, according to the situation in which a content is framed by a context. The interplay between phenomena, models and representations is relevant in all contextual settings, however with different specifications. In a professional situation, differentiated models are needed, while in a daily-life situation, basic models - if any - could be suitable. In a societal setting, models often combine chemical and other variables, like costs. Here, models with regard to statistics are needed, to name one example. The modes of representation also vary with regard to a contextual situation. A professional context uses representations that are often only understandable by experts, like mathematical or chemical formulae. In daily-life, terms and pictures are more common.

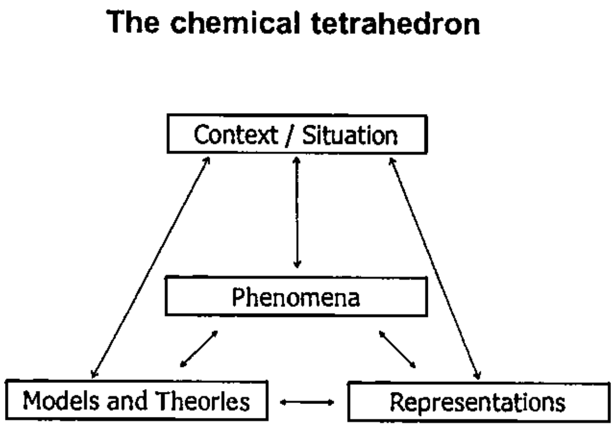

Figure 4. The chemical tetrahedron (adapted from Peter Mahaffy, 2006).

One goal of education therefore is to enable students to 'read' different representations, and to use them according to a context. This is a first step of becoming scientifically literate. De-coding and using models and forms of representations is one pre-requisite of the application of knowledge. The 'anchor' that a context sets towards a certain pool of knowledge (theories and models) is another, theoretically discussed by di Sessa (1988) and applied by the approach 'Anchored Instruction' (Cognition and Technology Group at Vanderbilt, 1990). The phenomena raised, observed and investigated are linked to this anchoring process. Again, further research is needed to better understand why and how a context in a broader, but differentiated sense, acts in a learning process.

Context-Based Chemistry: Citizenship and Responsible Research and Innovation

Context-Based Learning and Citizenship: Reflective Decision-Making

Decisions are made on arguments. These arguments, however, are not always based on knowledge and cognitive processes of evaluation; they are often at least equally based on implicit assumptions, emotions, and other factors like prejudices (Menthe & Parchmann, 2015). Following the argumentation explored before, CBL offers opportunities to develop the competence of reflective decision-making by including such processes into subject-related learning processes. Ideally, the reflection processes include different perspectives to point out the relevance but also the limitations of chemistry in a decision-making process. Students as future citizens have different roles throughout their lives and in a society; they should be able to act as a reflective practitioner in different situations.

The reflective decision-making can vary from decisions related to oneself (e.g., which potato chips should I buy, or should I make tattoos under my own skin; see also Marks, Bertram, & Eilks, 2008) to decisions related to the society (e.g., production of fuels presented above, or human behavior that influence the environment; see also Mandler, Mamlok-Naaman, Blonder, Yayon, & Hofstein, 2012). Hence, Cullipher, Sevian, and Talanquer (2012) suggested a learning progression sequence according to which the learner moves from 'responsibility to yourself' to the highest level of awareness and responsibility concerned with 'global processes and the environment'.

This process of reflective decision-making provides an authentic context to study chemical concepts. However, these decisions are usually leading to a certain behavior (e.g., buying or not buying potato chips; or using tap water rather than bottles of mineral water; see also Mandler, Blonder, Yayon, Mamlok-Naaman, & Hofstein, 2014; Menthe & Parchmann, 2015). These decisions are not meant to influence scientific research nor any innovative development. Namely the direction of influence is always from science to society. The scientific knowledge provides a guideline for how to behave and what to decide. In the recent years, additional directions of influence between science and society emerged (Owen, Macnaghten, & Stilgoe, 2012) as reflected in the movement for responsible research and innovation (RRI).

Context-Based Learning for Responsible Research and Innovation

Research of today is strongly connected to societal developments. The latter raise questions and demands; the first produces basic knowledge and, building up on that, scientific and technological applications. This iterative connection requires a strong and reciprocal exchange and co-operation between scientists, technologists and laypersons being active in other roles in a society.

The European Union currently sets a strong focus on the development of approaches and materials enabling school students, stakeholders and experts to better understand and to participate in processes of 'Responsible Research and Innovation' (RRI). Results from such projects build up on CBL approaches. The following example (Table 2) from the project IRRESISTIBLE (available at: http://www.irresistible-project.eu) shows how a unit can be designed, following an enlargement of Bybee's 5E-model, comparable to the four phases of *Chemie im Kontext*.

RRI asks for a reflection of parameters influencing professional and personal engagement in debates and processes of research and innovation relevant for societies as well as for individuals. In this framework, citizens are called to engage in the process of influencing the scientific process (Owen et al., 2012). In order to be able to take part in this process scientists are committed to provide open access to the developed knowledge and to be responsible to science education. This close connection between science and society and the involvement of societal organizations and NGOs (non-govemance organizations) requires scientific knowledge of the citizens and leads their needs to learn science (Blonder, Zemler, & Rosenfeld, 2016; Sutcliffe, 2011). CBL approaches have incorporated several equivalent goals in their reasoning, though not all of them. RRI can therefore be regarded as a step forward, starting from STS, SSI and CBL frameworks, moving again another step towards citizenship in an advanced and multi-perspective meaning.

Table 2. The '6E-model' of the project IRRESISTIBLE: example of unit on Oceans (available at: http://www.irresistible-project.eu)

Phase	Lessons	Content
Engage	1	Starting with a trailer showing flora and fauna of the ocean in fascinating pictures, followed by a PowerPoint slideshow, which gradually shifts from great pictures to touching photographs showing the impact of plastic on marine creatures.
Explore	3	Mystery: "Why is the health of the Larsson family in Greenland possibly in danger because they don't want to give up their traditional diet?" Students get ~16 fact cards with different arguments. In groups of 4 they analyze the arguments and try to create a path to solve the question. The game should give an idea of the complex relations playing together in the ocean.
Explain	2	As a result of the mystery, students describe a possible way how the Larsson's family is connected to the global problem of plastic waste in the ocean.
Elaborate	6	Pupils deal with further research questions about the local observation of the plastic problem. In this phase, pupils perform their own experiments, read scientific publications on the subject and confront extracurricular learning partners with questions. In the second part of the elaborate phase, the aspects of RRI are discussed in class, looking back and highlighting them in the module performed so far.
Exchange	~10	An exhibition is developed to exchange the gained knowledge with peer students and/or parents.
Evaluate	1	At this stage, the expertise of the students is checked with a test. This includes questions about both the global and the local view of the problem.

CONCLUSION

Context-based chemistry learning influences chemistry teaching and learning in several dimensions. This approach was developed as a response to the problem of low motivation for science learning and limited interest in school science. However, the influence of CBL went far beyond the affective dimension. CBL is also commenced to cognitive dimension of chemistry learning. The authentic context also provides an additional dimension: the human dimension that represents the interaction of people (e.g., the learners) with the chemistry in a certain context. This dimension introduces the learner to the decision-making in SSI and even goes beyond the personal decisions and influences the researchers as well as the learners when CBL is applied in the framework of RRI.

The CBL modified the way chemistry is taught: from teaching chemistry based on the structure of the content to teaching chemistry according to knowledge that is needed to comprehend a chosen chemistry-rich context. This characteristic was perceived to attribute CBL to school chemistry. However, the development of the chemistry discipline in the last years lead chemistry to be more involved in and relevant to the environment and the society (Matlin, Mehta, Hopf, & Krief, 2016), as reflected from the following citation taken form Seville International Chemistry Declaration 2016 (http://www.euchems.eu/seville-international-chemistry-declaration-2016/):

> "In a world that is becoming increasingly populated and urbanized, and which will require 30% more water and 40% more energy by 2030, we are faced with innumerable social challenges that require a firm commitment to research and innovation for their resolution. It will be chemistry as a discipline, with the fundamental and necessary support of other sciences and areas of knowledge, which will continue to assume the responsibility of addressing most of these challenges and to offer sustainable solutions." (np).

In this chapter, we demonstrated how CBL provides a natural platform to teaching chemistry with the integration of the human dimension as well.

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