Making chemistry meaningful: Conditions for successful context-based teaching

*Onno De Jong**

Abstract

During recent decades, a growing number of people have expressed their dissatisfaction with the quite isolated position of many science curricula: seen as hardly focusing on students' personal interest, society and technology issues, and modern scientific developments. To solve this problem of isolation, it was proposed to link school science content with context from everyday life, professional life, and so on. In older context-based approaches, contexts are only used as illustrations and applications. In more modern context-based approaches, contexts are also starting points for the learning process and have an orientation and motivation function. Although the use of contexts has a number of benefits, there are also several disadvantages. Both aspects will be addressed in this article, by presenting teachers' views and by reporting studies of effects on students' learning outcomes, motivation and attitude. Finally, important conditions for successful context-based science teaching are discussed.

The rise of contexts on the waves of science curriculum reform

In the last 50 years, several waves of science curriculum reform have occurred in many countries. An important starting point can be located in the middle of the Cold War era, in 1957, when the former Soviet Union launched the first satellite (the 'Sputnik"), into an orbit around the world. This evoked a shoc around the world, and showed the relative inferiority in science and technology in several other big industrialized countries, especially the USA. Educational experts pointed out that one of the main causes of the deficit was the relative low quality of the existing science curricula. They criticized the existing curricula by characterizing them as old-fashioned, overloaded, and mainly facts-oriented. Although this criticism was not very new, the 'Sputnik' effect made the policy makers more willing to listen to it and to invest much more money in the development of new national science curricula. Most of this reform was large-scale, for example, the North-American projects of Chemical Education Materials Study (CHEM Study) and Chemical Bond Approach (CBA), and the British project of Nuffield Chemistry. These leading projects for secondary schools focused on understanding basic chemistry concepts and rules instead of knowing a large number of chemistry facts, and for that reason, students got the opportunity to use special student data books. The new curricula also focused on stimulating the development of basic skills, and classrooms were adapted (or added) for conducting laboratory work. However, contexts for a better understanding of science were not widely incorporated in the curricula.

Although the expectations of the effects of the innovations were high, in general, the results were quite disappointing. For instance, the increase of students' enrolment in first-year university science courses was modest, and many secondary school students continued to complain that the new curriculum content was difficult to understand and not very interesting to them. The failure of these curriculum reforms can be seen to be caused by several factors; one of the main causes concerns the strong focus on the existing 'body of knowledge' of science from the expert perspective, rather than from the student perspective. Because of the disappointments of the 1960s reform and stimulated by an alarming report from the USA, 'A Nation at Risk', 1983, a second wave of curriculum innovations were initiated. In this reform, most projects were smaller scale, for example, the North-American project of 'Chemistry in the Community' (ChemCom), and the British Salters' Chemistry project. In the 1980s reform, the design of most courses was much more student-oriented and 'active learning' approaches were adopted much more. Moreover, efforts were made to make science more meaningful to students by relating concepts and rules to situations from everyday life that were believed to be of interest for students. In other words, contexts were adopted to

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* Utrecht University, Centre for Science and Mathematics Education, Princetonplein 5, 3584 CC Utrecht, The Netherlands.
E-mail: O.deJong@phys.uu.nl

encourage a more positive attitude and a better understanding of science.

Despite all these innovations, the results of this wave of curriculum reform were also quite disappointing. For instance, the enrolment in first-year university science was decreasing, and many secondary school students did not see the relevance of the given contexts for understanding the related concepts and rules. In order to solve the reported difficulties, about 5-10 years ago, a third wave of curriculum innovation projects came up. Some examples are the North-American project of 'Chemistry in Contexts: Applying Chemistry to Society' (CiC), and the German project of 'Chemie im Kontext' (ChiK). This new generation of projects aims to use contexts that really are relevant for students. The projects are still evolving, and, for that reason, it is too early to evaluate the value of the recent reform properly.

In the present article, contexts and their use at the level of secondary science education, especially chemistry education, are addressed. First, the sources of context are discussed in terms of four different domains of interest. Then, several relationships between contexts and concepts are given. Thereafter, benefits and disadvantages of the use of contexts are reported by presenting teachers' views and by reporting studies of effects of context-based teaching on students' learning outcomes, motivation and attitude. Finally, important conditions for successful context-based science teaching are discussed.

Contexts and domains of origin

Contexts can be defined in several ways. Very often, contexts are described as situations that help students to give meaning to concepts, rules, and so on. In my opinion, this definition can be expanded by the notion that contexts can also be described as practices that help students to give meaning to activities in the school laboratory, such as inquiry and designing. Contexts can be classified by looking at the domain of origin. I would make the following distinction (seeTable 1).

Table 1. Four categories of contexts.

- Contexts from the personal domain.
- Contexts from the social and society domain.
- Contexts from the professional practice domain.
- Contexts from the scientific and technological domain.

a) Contexts taken from the personal domain are important because schools should contribute to the personal development of students by connecting science with their personal lives. Many everyday life issues are useful. For instance, the context of clothes can be linked with the chemical properties and structure (and their mutual relationship) of wool, cotton, or plastics. Other examples are the context of personal body care and appearance that can be related to the biological topics of skin, hair, and teeth, and the context of listening to music that can be connected with the physics concepts of sound and its transmission.

b) Contexts taken from the social and society domain are important because schools should contribute to prepare students for their roles as responsible citizens by clarifying science and its role in social issues. Many of these issues can be used. For instance, the context of interpersonal communication can be related to the physics concepts of light and the electromagnetic spectrum. Other examples are the context of transfer of infectious diseases that can be linked with the biological concepts of bacterium and virus, and the context of acid rain effects on the environment that can be connected with the chemical topics of acid-metal reactions and neutralization reactions.

c) Contexts taken from the professional practice domain are relevant because schools should prepare students for their coming role as professional workers in public or private areas. Several practices are useful. For instance, the practice of (bio)chemical analysts or scientists can be related to the (bio)chemical topic of investigating the quality of water, food, or medicines. Another example is the practice of engineers that can be linked with small scale designing and testing of constructions, such as metallic bridges or electronic circuits.

d) Contexts taken from the scientific and technological domain are relevant because school should contribute to the development of scientific and technological literacy of students. Several issues can be used. For instance, the context of organism in the environment can be related to the topics of natural and artificial ecosystems and the factors that sustain or threaten the balance of organism within the environment. Another example is the context of energy demands in society that can be linked with the topic of the costs of energy and the consequences of unlimited use of energy sources. In pre-university schools, students should also be oriented to current scientific and technological issues at the university. Often, it will not be easy to relate the current issues to the level of school science and technology. This difficulty may be solved by using contexts taken from the history of science and technology.

Finally, it will be clear that a particular context can be taken from more than one domain. For instance, the context of driving a car can come from the personal domain as well as from the social and society domain.

Relationship between contexts and concepts

A one-to-one relationship can exist between contexts and concepts, but multiple relations are also possible (see Figure 1). For instance, the context of the greenhouse effect can be linked with several concepts, such as the chemical concept of gas reactions and the physics concepts of infrared radiation and heat. Conversely, one concept can be related to several contexts, for instance, the concept of tap water can be linked with a personal/society context as well as a scientific/chemistry context. Note that the meaning of a concept can vary with the related context. For instance, in a personal/society context, tap water is considered as pure because it looks clear and it is safe to drink (according to the requirements of the law), but in a scientific/chemistry context, tap water is not defined as pure because it will contain small amounts of substances.

Another kind of relationship between contexts and concepts is the order of presentation in teaching. This order can vary, and, for that reason, the function of contexts can also vary (see Figure 2). In quite traditional approaches in the context-based teaching of science and technology, two functions of contexts are dominant. Firstly, contexts are presented as illustrations of concepts that already have been taught, especially in the case of abstract concepts. Secondly, contexts are presented to offer the possibility to students of applying their knowledge of a concept. This can lead to the transformation of the existing meaning of a concept or to the addition of a new meaning to the concept. In more modern approaches, two other functions of contexts are emphasized. Firstly, contexts are presented as the starting point or rationale for teaching concepts. Secondly, these contexts not only have an orienting function, but can also enhance motivation for learning new concepts. Finally, it will be clear that a combination of both orders of presentation of contexts is also possible.

Teaching chemistry by using multiple contexts: an exemplar

Most context-based projects use contexts from personal and/or social life only, whereas projects that select contexts from professional practice life and/or the scientific and technological domain are quite scarce. A recent example of a small-scale project that combines contexts from all four domains is described by Van Aalsvoort (2004). She developed a series of learning units for secondary school classes of grade 9 (students aged 14-15). An exemplar learning unit is 'water'; a concise overview is given below.

The unit started with addressing an issue from the personal domain, namely the individual need for water. This context is expanded to a social and society context by asking the students to discuss the need for water in households (for instance, because of cleaning things) and companies (for instance, because of producing food). Then, a technological context is introduced. In the school laboratory, the students have to prepare drinking water from a given amount of ditch water. When designing a plan for this task, they are allowed to use given information

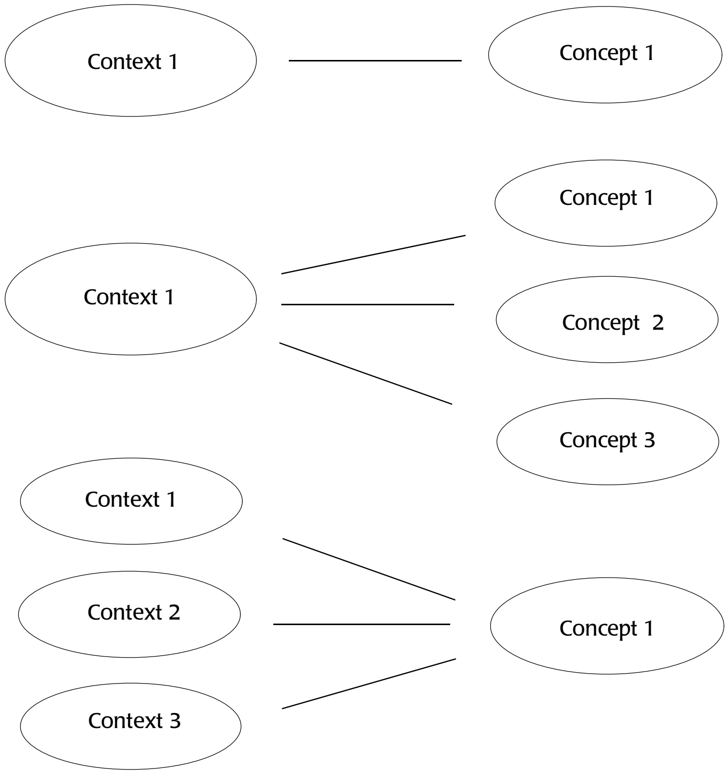

Figure 1. Single and multiple relationships between contexts and concepts.

about the technologies that are used in waterworks producing drinking-water from ground water or surface water. After finishing their laboratory activities, the students are asked to check whether the quality of their drinking-water is acceptable, by comparing the results of a quality test of their drinking-water with the formal demands in the law. By doing this, a professional practice context is introduced, namely the role of chemical analyst. In the next part of the unit, another professional role is introduced: the chemical researcher. In the school lab, the students take this role when they have to investigate the effectiveness of a number of adsorption agents for the removal of colours that are dissolved in water (the colours represent the presence of pesticides in water). Finally, the students are asked to play the role of chemical engineer. Their task is to design a waterworks for a poor and dry area where groundwater is of a very bad quality and seawater is the only available raw material. As before, the task should be carried out in small groups and the results should be presented to the other groups, and discussed during a plenary in class.

The series of learning units mentioned above has been tried out in classes, but research into the effects of this contexts-based approach compared with more traditional approaches is still lacking.

Teachers' views on context-based science teaching

Although nearly every science teacher has his or her personal opinion about the value of context-based teaching, only a few studies have explored teachers' views in a systematic way. Two exemplar studies are discussed below.

Recently, Bennet, Gräsel, Parchmann and Waddington (2005) reported about teachers' views by comparing two groups of British chemistry teachers. The first group of teachers had experience with teaching a particular context-based course, namely Salters Advanced Chemistry. The other group of teachers had experience with teaching conventional chemistry courses only, but it was known that most of them have studied the Salters' course materials. The results of the study showed that, in general, both groups agreed that context-based teaching had positive effects on students' motivation and interest and that student taught by this approach would be more likely to go to university to study chemistry. Both groups also agreed that students following a context-based course would be better able to study independently but would find it more demanding to study chemistry. However, the results also indicated differences in views between the two groups. The conventional course teachers were unconvinced that the context-based course delivered the concepts in sufficient depth. In contrast, the Salters' course teachers believed that their course did indeed cover the concepts adequately and that there were significant advantages in using the context-based approach as a good foundation for further study at the university.

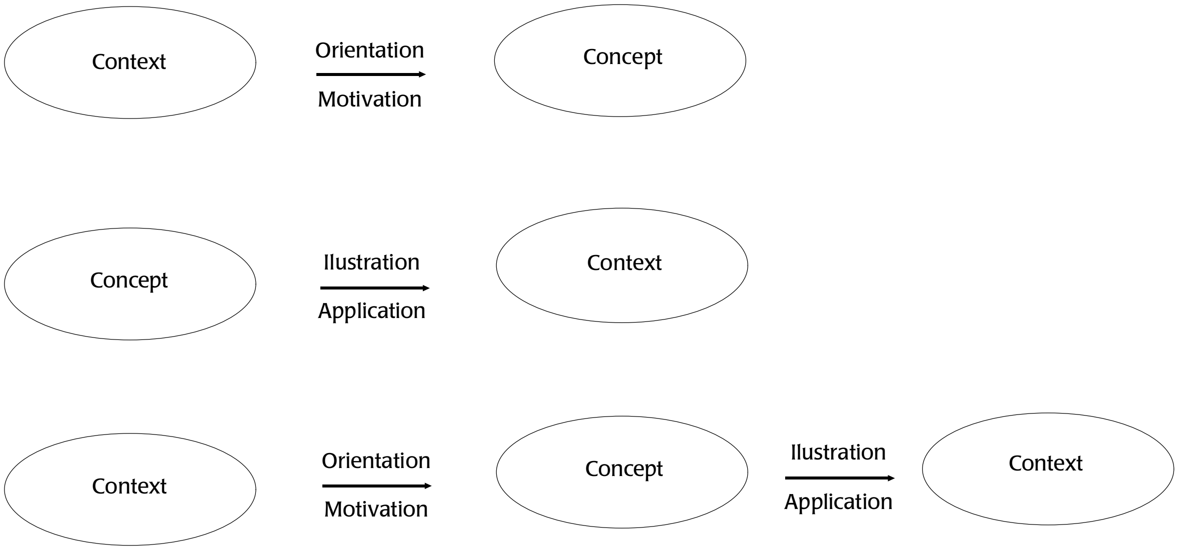

Figure 2. Variations in the order of presentation of context and concepts.

In an older study of teachers' views, British science teachers reported definite improvements in the general classroom atmosphere when the context-based course was introduced (Ramsden, 1994).

In general, studies of teachers' views showed that science teachers have positive thoughts about the influence of context-based teaching on students' interest, but they think differently about the impact on students' learning outcomes. For a well-founded judgment about benefits and disadvantages of context-based science teaching, it is necessary to complement the studies of teachers' views with studies that investigate the effects of this teaching more directly, especially to clarifying the discrepancies in views about students' learning outcomes. This research is addressed concisely in the next section.

Effects on students' learning outcomes, motivation and attitude

Most of the studies of effects of context-based approaches in science education focus on students' learning outcomes, and students' motivation and attitude. The research results show that it is not easy to come to a unanimous judgment about these effects. I will clarify this by presenting results of some exemplar studies below.

Several studies indicate that there is hardly any advantage of context-based courses in terms of the development of students' understanding. Rubba, McGuyer and Wahlund (1991) showed that the use of societal contexts did not improve North-American high school students' understanding of the topic of genetics. Ramsden (1997) compared the effects of a context-based course and a more traditional course to British high school students' understanding of key chemistry concepts. Her study also indicated that there is little difference in levels of understanding of concepts as element and compounds, chemical reaction, and the Periodic Table.

In contrast, other studies report advantages to students in context-based courses in terms of their understanding. Barker and Millar (2000) undertook a comparative study of British high school students following a context-based course or a conventional course. They found a slight advantage in developing understanding (about chemical thermodynamics and chemical bond) of students in the context-based course. Nevertheless, they also reported the tenacity of a number of misunderstandings among students of both groups. Dahncke, Behrendt and Reiska (2001) compared the effects of a context-based course and a traditional course to high school physics students in Germany and Estonia. Their study indicated that the students in the context-based course (in both countries) developed a better understanding of the concept of energy.

Some studies have also looked at effects on students' motivation and attitude. The comparative study of Ramsden (1997), dealing with British high school chemistry students, showed some benefits associated with a context-based approach in terms of stimulating students' interest in chemistry. Sutman and Bruce (1992) noted that North-American high school students were much more willing to engage with context-based chemistry materials than with more traditional materials.

A summarizing meta-analysis of 66 studies of the effects of context-based approaches is given by Bennett, Hogarth and Lubben (2003). They reviewed studies of approaches that use contexts as the starting point for the development of scientific ideas. The majority of the courses under consideration came from the USA, the UK, The Netherlands and Canada. Their in-depth systematic review showed that there is some evidence to support the claim that context-based approaches motivate students in their science lessons. There is also evidence to support the claim that such approaches also enhance more positive attitudes to science more generally. Finally, the review results showed that there is good evidence to support the claim that context-based approaches do not adversely affect students' understanding of scientific ideas.

In conclusion, the outcomes of context-based science teaching are positive from an affective development perspective, but they may be somewhat disappointing from a cognitive development point of view. Regarding the latter result, I would point out that a comparison between context-based approaches and traditional approaches has methodological limitations. It may be that the cognitive effects of context-based approaches are not only better or poorer than traditional approaches, but also cover effects that differ in another way. For instance, the kind and number of students' conceptual difficulties may differ between approaches. New research is needed to explore the presence of this extra effect.

Conditions for successful context-based science teaching

In the last section, I will address some conditions for successful context-based teaching from three different perspectives: (i) the student, (ii) the curriculum, and (iii) the professional development of teachers.

From the student perspective, I would point out the importance of selecting adequate contexts for incorporating in student courses, especially when contexts are used as starting points for teaching concepts. These contexts should take into account students' specific difficulties in relating contexts to concepts. These difficulties have different possible causes. First, the contexts may be not really be relevant for students and will not motivate them to study the science content. For instance, the use of a technological context as the construction of a machine will not stimulate many school girls to study the accompanying physics, while the use of a personal life context as the properties and composition of several kinds of lipsticks and other cosmetics will not be an interesting issue for many school boys. Second, and in contrast with the former cause, the contexts can be so interesting that they distract students' attention from the related concepts. Third, the contexts can be too complicated for students to help them to make proper links with concepts. Finally, the contexts can be confusing for students, because everyday life meanings of topics do not always correspond with science meanings. For instance, the acidity of acid rain is expressed in a number (pH); in everyday life, people will reason that a high acidity will correspond with a high number, but in science this acidity should have a low number. Other examples are the topics of energy and force. In an everyday life context, people talk about the global energy stock that is going down, while in science the conservation of energy is a basic idea. In the same context, it is usual to connect the topic of force with movement only, while in science the term force has also meaning regarding non-moving objects.

In conclusion, an important condition for successful context-based science teaching is a careful selection of contexts. Their introduction and use should be accompanied with a lot of care for bridging the gap between meanings of topics in a context setting and meanings in a science setting.

From the curriculum perspective, I would point out the importance of a proper position of contexts in science curricula. The structure of many modern curricula is still based on the conventional relationship between school science topics; contexts do not have a central position. Because of this situation, students and teachers are not inclined to take contexts very seriously. For instance, when contexts are used as post-theory illustrations of topics, many students do not see these illustrations as meaningful, because they know that very often the illustrations are not incorporated into testing and assessment. Moreover, many teachers consider the illustrations in textbooks as useful for learning but they see the teaching of them as too time-consuming and skip many of them.

In conclusion, an important condition for successful context-based science teaching is a more dominant position of contexts in curricula, but without loss of attention to science concepts. This can be realised by developing curricula in which contexts are the lead in determining the curriculum structure of science topics.

From the teachers' professional development perspective, I would point out the importance of helping teachers to undertake context-based teaching in a successful way. In a study of a teacher development course for teaching chemistry concepts in contexts, Stolk, Bulte, De Jong and Pilot (2005) found that it is quite difficult for experienced teachers to link an introductory context (about properties of diapers–pañal in Spanish) with chemistry content (property-structure relations of polymer networks). The aim of this experiment was to evoke students' 'need-to-know' about the chemistry beyond. However, after the experiment, the teachers did not use students' questions about the phenomena (surprising amount of liquid uptake by the diaper) as a starting point for linking with relevant chemistry concepts, but referred directly to a general chapter about organic chemistry in the students' textbook. In other words, after the introductory experiment, they taught according to their familiar routines in teaching.

In conclusion, teachers' professional development courses should relate course activities with context-based teaching practices at school, they should provide teachers the opportunity to adapt 'half-finished' context-based materials and to complete them for classroom implementation, and they should stimulate teachers to discuss and reflect on teaching difficulties with their colleagues.

Finally, I would emphasize the importance of combining research projects with teacher courses to investigate a number of relevant problems, such as: what contexts are fruitful for learning science, how to teach for linking contexts with concepts successfully, and how to guide teachers to make science real meaningful for students.

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