New Chemistry: context-based modules and pathways in a bottom-up project of curriculum reform

New Chemistry: mòduls i itineraris basats en el context en un projecte de la reforma curricular amb enfocament de baix a dalt

Onno de Jong / Utrech University. FISME Institute (the Netherlands)

abstract

A national curriculum reform project on context-based chemistry teaching in the Netherlands is presented. The New Chemistry curriculum was developed by using a bottom-up approach: teachers designed and tested context-based modules based on a specific format. Thereafter, the modules were put online. Modules were combined into three characteristic teaching-learning pathways. Examples of modules and a pathway are given. Teachers' experiences and opinions regarding New Chemistry are also reported.

keywords
Chemistry curriculum, bottom-up reform, New Chemistry project, context-based modules, modular teaching, learning pathways.

resum

Es presenta un projecte nacional de reforma curricular en l'ensenyament de la química en context als Països Baixos. El currículum del projecte New Chemistry va ser desenvolupat utilitzant un enfocament de baix a dalt. Els professors van dissenyar i provar els mòduls basats en el context en un format específic. Després, els mòduls es van publicar en línia. Els mòduls es van combinar en tres itineraris d'ensenyament i aprenentatge característics. Es donen exemples de mòduls i d'un itinerari. També s'informa sobre les experiències i opinions del professorat respecte del projecte New Chemistry.

paraules clau
Currículum de Química, reforma amb enfocament de baix a dalt, projecte New Chemistry, mòduls basats en el context, ensenyament modular, itineraris d'aprenentatge.

Introduction

This article deals with the recent development of a complete new chemistry curriculum for senior secondary schools in the Netherlands. The need for this reform was mainly evoked by an alarming report on serious problems in Dutch school chemistry education (Koten *et al.*, 2002). A summary of the major four problems is given in table 1.

Table 1. Major four problems in Dutch school chemistry education

- The image of the chemistry discipline is quite negative.
- School chemistry does not intrinsically motivate students.
- The inspiration of chemistry teachers is decreasing.
- Measures to improve the quality of chemistry education are weak.

The problems presented in table 1 were neither typically Dutch nor restricted to chemistry education, but were also found in many other countries and other science education (Osborne & Dillon, 2008).

The curriculum development started in 2004, when a Steering

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Committee on New Chemistry was established by the Dutch Ministry of Education, Culture, and Science. This committee launched a curriculum reform project focusing on reducing or solving the reported problems. The first two problems in table 1 were attacked by introducing a context-concept strategy for teaching chemistry. According to this approach, situations or issues from a variety of domains (personal, societal, scientific, technological) are related to relevant chemistry concepts and processes. This approach can be promising because a meta-study of Bennett, Lubben & Hogarth (2007) has indicated that context-based science teaching can contribute to improve students' motivation and to foster positive attitudes toward science in general.

The last two problems in table 1 were attacked by involving chemistry teachers from an early stage of the development process. This way of involvement can be promising, because it was found that reform in science education in the past has often been not very successful when the projects failed to take teachers' existing knowledge, belief, and attitude into account (Driel, Beijaard & Verloop, 2001).

Context-based teaching and bottom-up development are approaches that are also applied by other modern reform projects, especially the German project Chemie im Kontext (Parchmann & ChiK Project Group, 2009), and the UK project *Salters advanced chemistry* (Otter, 2011). Experiences from both projects were used as input in the early stage of the Dutch project.

Finally, the Steering Committee also launched a pilot project in which a draft version of the complete curriculum was implemented in several senior secondary schools during 2007-2010. The New Chemistry project came to an end in 2010, when the committee published a final report (Apotheker *et al.*, 2010). The new curriculum was accepted by the Ministry in 2011. The first national final chemistry examination based on this curriculum will take place in 2015. At that time, it will be possible to evaluate the complete curriculum properly.

Note: much information in this article is based on the final report of the Steering Committee, other project-related documents, and relevant research publications.

The bottom-up approach of the project

In the project, small teams of chemistry teachers from five to eight schools designed one or more context-based modules. Each team was guided by a coach, often a teacher educator, and was part of a larger regional network for exchanging experiences. The drafts of the modules were tested in classrooms by the teacher-designers or other teachers. The results were reported and discussed in the designing teams for revision purposes. In this way, the teams functioned as fruitful «communities of learning». The coaches formed an expert group which also functioned as a learning community. An overview of the cooperation between teacher teams and coaches is given in fig. 1 (taken from Apotheker *et al.*, 2010, p. 85).

Teacher-designers and field testers can be considered as «innovators» in the curriculum process. Other groups of teachers also fulfilled the role of innovator. Beside them, there were teachers who can be identified as active or passive «followers», such as visitors of conferences and workshops (fig. 2). An overview of all categories of participating teachers and their schools is given in table 2.

The New Chemistry modules

Nearly sixty context-based modules were designed by the teachers. Each module consisted of a student booklet, a teacher guide, and often a booklet of resources. Examples of these modules are: «Energy to take away» (redox-reactions, electrochemical cells), «Perfume» (esters, alkenes, alcohols), and «The Nobel prize

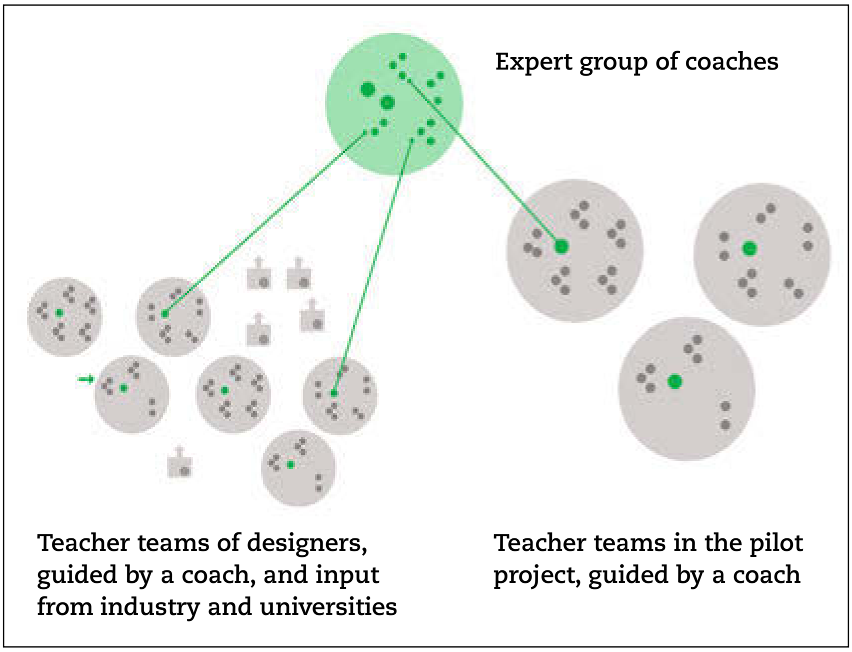

Figure 1. Diagram of the cooperation between teacher teams and coaches.

Table 2. Chemistry teachers as participants of the curriculum process

Role of teacher	*Participating schools**
Innovator: – Designer, field tester, or user of context-based modules. – Participant of the pilot project on the complete curriculum.	– 211 schools, incl. overlap. – 19 schools.
Active follower: – Visitor of conferences and workshops. – Visitor of protected parts of the project website (password).	– About 250 schools. – About 150 schools.
Passive follower: – Visitor of open access parts of the project website. – Reader of New Chemistry articles in teacher journals.	– Unknown number of schools. – Unknown number of schools.

* Each school delivered one or more teachers (number per school not given in the committee's report).

Figure 2. Visitors of a conference on New Chemistry.

and the atom» (atomic structure, periodic table). These examples and some other modules are available in Dutch at the free access project website: *http://www.nieuwescheikunde.nl/Publicaties/Lesmodulen*. All other modules could only be entered at protected links of the project website by using a password. All suggested modules were intended to function as examples of teaching and learning New Chemistry. Teachers were free to adopt the modules, to adapt them, or to replace them by other materials.

The provided modules were often structured by using a slightly adapted version of a format taken from the German Chemie im Kontext project (Parchmann & ChiK Project Group, 2009). A summary of this version is given in table 3.

Table 3. Usual format of a context-based module

Phase	*Major characteristic*
0. Orientation to the module	– Name of the module and general learning goals. – Main instructional format.
1. Introduction to the context	– The leading context question. – Introductory activity.
2. Selection of specific questions	– What specific questions are interesting? – What new knowledge is needed? – What plan of activities?
3. Development of new knowledge	– Executing (practical) activities. – Answering the leading context question.
4. Abstraction and transfer of knowledge	– Reporting about the module. – Summarizing the new chemistry knowledge. – Addressing possible applications.

An elaboration of the format from table 3 is given below for the module «The Eco-travelling Company: the trip», for students of grade 10 (age 16). This module (about fourteen lessons) can be found under the Dutch name «Ecoreizen BV: de reis» (fig. 3) at the free access project website mentioned before.

In the pre-phase of *orientation to the module* about eco-travelling, students were concisely informed about the name of the module, the general learning goals, and the main instructional format. They also got a student booklet and a resource booklet.

In the phase of *introduction to the context*, students were told that the Eco-travelling Company (a fictitious name) has launched a call for a competition about the question: «What is the most sustainable trip of thirty days around the world?». This question was the lead of the module. Students were asked to read the general conditions from the travel company such as the condition that

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traveling should go on all continents and between them, and the condition that the answer should be evidence-based.

In the phase of *selection of specific questions*, students were asked to discuss what they wanted to know about the idea of *sustainable trips* and how they might find answers to their questions. Subsequently, students were offered descriptions of a set of activities. After a short look at this information, they were asked to set up a preferred order of the given activities, and to design a plan for inquiry. The latter should be discussed with the teacher for approval.

In the phase of *development of new knowledge*, students were asked to work on the planned activities such as calculating the amount of a specific type of fuel that would be needed for particular trips. Follow-up calculations regarded the amount of CO_2 that would be emitted for each type of fuel. The latter calculations not only required knowledge of formulas of carbon chemistry substances, but also knowledge of stoichiometric calculations including the concepts *mole*, *molar mass*, and *molar volume*. Students were asked to read texts about these concepts, and to carry out practical quantitative experiments related to a particular continent. For instance, regarding Africa, students have to determine the percentage vitamin C in pills. Near the end of this phase, students were asked to read texts about sustainability, to design examples of ecological cyclic processes, and to discuss criteria for a sustainable trip. Finally, students were asked to answer the leading context question.

In the phase of *abstraction and transfer of knowledge*, each group of students was asked to prepare an evidence-based flyer about an ecological sound trip around the world in thirty days. Each group was also asked to write a summarizing report on their work, including the chemical calculations, to present the report to other students, and to address possible applications.

Figure 3. Cover of the student booklet «Ecoreizen BV: de reis».

Finally, some New Chemistry modules were translated into English by a special foundation and were available at other free access websites. For instance, the module «Green chemistry» (energy balances, atom economy, process chemistry) can be found at: *http://www.studioscheikunde.nl/havovwo_bb/Module_Green_Chemistry/*. Another example, the module «How can we eat healthily» (carbohydrates, fats, proteins) is available at: *http://www.studioscheikunde.nl/havovwo_bb/Module_How_can_we_eat_healthily/*.

Modular teaching-learning pathways

In order to facilitate students' learning of connecting contexts with concepts, the Steering Committee (Apotheker *et al.*, 2010) suggested to cluster modules in pairs in which chemistry concepts were introduced and elaborated in successive contexts. Each pair of modules would be followed by a bridge module in which the chemical concepts were further abstracted from the contexts and new questions could be addressed. Examples of paired modules and related bridge modules are given in table 4.

When chemistry teachers select (paired) modules from the project website for use in their classroom, they will look for those modules that fit their personal conceptions of chemistry teaching and learning. They are free to decide the order of the selected modules. In order to support teachers, the Steering group, together with the expert group of coaches, combined modules to three different categories of teaching-learning pathways (strings). These categories can be summarized as follows:

— *«Chemistry, technology, and society» teaching-learning pathway*. This category fits conceptions of teachers who prefer to use interesting socio-scientific issues as contexts for developing and applying students' knowledge of related chemistry concepts and processes. They want to pay special attention to explore socio-scientific alternatives such as the sustainable issue.

— *«Knowledge development in chemistry» teaching-learning pathway*. This category fits conceptions of teachers who prefer to use experiments and historical resources as contexts for developing and applying students' knowledge of how chemistry concepts and processes are and have been developed. They want to pay special attention to the nature of chemistry such as the function of models and the role of paradigms.

— *Mix of the two foregoing pathways*. This category fits conceptions of teachers who want to combine modules from the first pathway with modules from the second pathway.

An example of a «Chemistry, technology, and society» teaching-learning pathway is given in table 4. This pathway is intended for teaching students of grade 10 (age 16), and covers the chemistry curriculum for one school year. The collection of pathways is intended to offer options to teachers. They can adopt any pathway, but are also free to adapt a pathway or to replace it by another series of modules.

Table 4. Example of a «Chemistry, technology, and society» teaching-learning pathway

Module	*Leading context question*	*Major concept*
New materials.	Does unbreakable pottery exist?	Macro: structure-property relations. Meso: constituent grains of materials.
Rescuing diapers in case of fire.	How to prepare a fire-resistant means from diaper constituents?	Macro: structure-property relations. Absorption. Meso: fiber structures. Networks. Micro: polymers. Crosslinks (H-bridge).
Bridge module.	What do we have learnt?	Concept maps. Exercises. New questions.
Eco-travelling: the trip.	How to calculate the most sustainable trip of thirty days around the world?	Introductory organic chemistry. Mole. Molar mass. Molar volume. Stoichiometric calculations. Sustainability.
Eco-travelling: the fuel.	How to produce biofuels?	Follow-up organic chemistry. Bonding. Calculations of reaction energy. Biofuels.
Bridge module.	What do we have learnt?	Concept maps. Exercises. New questions.
Plants from the earth.	What do plants need?	Salts and ions. Precipitation reactions. Calculations on solutions. Fertilizers.
Growth and agriculture.	How to do sustainable agriculture?	Electrolytes. Determining ions in solutions. Adsorption. Herbicides.
Bridge module.	What do we have learnt?	Concept maps. Exercises. New questions.
The scooter of today: inquiry.	What is the composition of a scooter?	Redox reactions. Electrochemical cells. Catalysts. Polymers. Metals. Corrosion. Structure-property relations.
The scooter of the near future: designing.	How to design a prototype of a fast, clean, and efficient scooter?	Greenhouse effects. Bonding. Chemical calculations. Technical design criteria. Technical sketching.
Bridge module.	What do we have learnt?	Concept maps. Exercises. New questions.

Teachers' experiences and opinions

Teachers' experiences and opinions regarding the context-concept approach, especially the New Chemistry modules, were reported in several studies. Representative results are concisely presented below.

— *Problems with connecting contexts with concepts*. Stolk *et al.* (2011) reported that teachers encountered difficulties in handling students' specific questions about the context (phase 2 of the module format; see table 3). In a follow-up study, the researchers found that teachers solved this problem by designing a set of do's and don'ts for selecting and reformulating these questions in such a way that students were encouraged to find answers by using appropriate chemistry concepts (Stolk *et al.*, 2012).

— *Concerns about the value of context-based modules*. Coenders *et al.* (2010) reported that teacher-designers initially wondered whether it would be possible to develop context-based modules for students to acquire knowledge of chemistry concepts. Extensive discussions during meetings reduced their concerns, and, after teaching, they became more convinced about the positive value and possibilities of the context-concept approach.

— *Growing appreciation of context-based teaching*. Ottevanger *et al.* (2011) found a growing appreciation of context-based teaching among teachers participating in the pilot project on teaching the complete curriculum.

— *Positive and negative opinions about New Chemistry modules*. These opinions were reported in a study by Woude and Grinsven (2010). Main results are summarized in table 5.

In conclusion, the reported studies have limited value, because they only regarded the development period of the reform. However, at the moment, this curriculum is implemented nationwide. This offers an important opportunity to collect more information about the enactment and the results of New Chemistry

Table 5. Chemistry teachers' opinions about New Chemistry modules

Positive opinion	*Negative opinion*
Closer links with students' everyday life.	A lot of preparation time is required.
Motivating teachers and students.	Absence of teacher book about modern contexts.
Room for personal teaching preferences.	Quality of modules is insufficient guaranteed.

Looking backward, looking forward

The development of the new curriculum did not occur top-down but used a bottom-up approach. As a consequence, participating teachers can be considered as co-owners of the curriculum reform. They participated in a range of roles: from motivated innovators who designed modules to passive followers who only read New Chemistry articles in journals. This participation covered several hundreds of chemistry teachers. This is about one-third of the entire target group. Although the number of involved teachers looks not really large, it is large enough to provide the new curriculum a firm base of evidence.

The New Chemistry project wanted to reduce or solve the problems of a quite bad image of chemistry and a low student motivation by introducing context-based modules and pathways. Studies suggested that the new approach indeed reduced both problems, at least it contributed to improve students' motivation for learning chemistry.

The project also wanted to attack two other problems: a decreasing inspiration of teachers and weak measures for improving chemistry education. To cope with these problems, a bottom-up development approach was applied which offered teachers the opportunity to design modules and pathways that take their conceptions of teaching chemistry into account. Investigations indicated that teachers really appreciated this approach. However, to what extent the quality of chemistry education was improved is still unclear.

In conclusion, the reported studies have limited value, because they only regarded the development period of the reform. However, at the moment, this curriculum is implemented nationwide. This offers an important opportunity to collect more information about the enactment and the results of New Chemistry.

Finally, curriculum innovations, as many innovations, run step-by-step. Teachers need time for becoming familiar with new teaching, as they indicated by complaining about the amount of required time for preparing their

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new lessons. They also need support by providing them with teacher resource booklets with information about modern contexts. These needs emphasize the importance of further professional development of all teachers. This can be realized in several ways, for instance by inviting teachers to visit relevant conferences and workshops or by asking them to participate in small (regional) networks of interested colleagues («communities of learning»). They can also be stimulated to read relevant articles in journals as the online journal *Chemistry Education Research and Practice* (free access: *http://www.rsc.org/cerp*).

In conclusion, the continuous professional development of chemistry teachers, supported by adequate research, can function as an important cornerstone of further reform of chemistry curricula in the near future. This is not only valid for the Netherlands, but also for other countries which are involved in context-based chemistry teaching.

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Onno de Jong

Was a chemistry teacher in schools before moving into teacher education and research at Utrecht University (the Netherlands). Later, he got a position as professor of chemistry education at Karlstad University (Sweden). He also worked as invited scholar at universities in South Africa, Malaysia, Australia, and Taiwan. He has ongoing interest in empowering teachers for handling innovations and in bridging the gap between *theory* (given in chemistry teacher courses) and *practice* (in chemistry classrooms).

E-mail: *o.dejong@uu.nl*.