THE DEVELOPMENT OF A NEW CHEMISTRY CURRICULUM IN THE NETHERLANDS: INTRODUCING CONCEPT-CONTEXT BASED EDUCATION

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ABSTRACT

This paper describes the recent changes in chemistry education in secondary school in the Netherlands. The way these changes came about is described as well as the development of the current curriculum. An example of a module, demonstrating the current features of chemistry teaching in the upper level of secondary school is given. *[AJCE 4(2), Special Issue, May 2014]*

INTRODUCTION

The educational system in the Netherlands underwent a major change in 1998. Up to then students in secondary education took a final exam in 7 subjects. The subjects Dutch, English, and Mathematics were compulsory. These subjects are considered to be basic knowledge that each student should have after finishing secondary education. The other 4 subjects were almost completely free of choice. If students choose the subject Chemistry, students followed on the average 3.5 50 minute lessons of chemistry per week during their last three years. The chemistry curriculum was set up broadly focusing mainly on inorganic chemistry, with a short introduction into first and second law of thermodynamics and some organic chemistry.

MAJOR CHANGES IN SECONDARY EDUCATION

In 1998 four majors were introduced, of which two were society-oriented and two were science-oriented. At the same time the number of subjects to be studied was increased to 14 in the last 3 years. For all subjects this lead to major changes in the curriculum. Most specifically in the amount of time available for each subject. Chemistry went back from 3 or 450-minute lessons per week to about 250-minute lessons per week in the final three years. Because of this time limit a number of subjects were deleted from the curriculum. Examples of scratched subjects are reaction mechanisms in organic chemistry, but also the concept of free Energy was no longer part of the curriculum.

The change led to major problems for teachers [1]. Teachers had difficulty adapting to the new chemistry curriculum, which was determined top down. They felt the curriculum was not set up logically. They disagreed with the deletions and were basically disappointed with the reduction in time for their subject. They then ran into time problems because they tried to teach all the concepts of the old curriculum in about half the time.

Identification of the problems

Based on these first developments the 'first van Koten committee' was asked to identify the current problems with chemistry education in pre-university education [2]. One of the most important conclusions was that the chemistry curriculum in secondary schools was outdated. It was still based on the original curriculum of 1848, when chemistry was first introduced in secondary education in The Netherlands. Furthermore, there was virtually no link with the role of chemistry in society today and the curriculum did not give an overall picture of the type of research being done in universities. On the other hand, less and less students chose a science-oriented major in secondary education.

In a next report the 'second van Koten committee' proposed a set of recommendations for a new chemistry curriculum [3]. Van Koten was then asked to prepare a new chemistry curriculum. This new curriculum was published in 2010 [4] and in 2011 accepted by the Ministry of Education. Since September 2013 this chemistry curriculum is implemented in the upper level of secondary schools.

THE NEW FORMULATED CHEMISTRY CURRICULUM

The new chemistry curriculum is implemented in the last three years of the upper-level of pre-university secondary school. The curriculum consists of several modules. The new curriculum has a number of basic principles. It:

- is context oriented

- connects macroscopic phenomena to the molecular and atomic level
- demonstrates the role of chemistry in society
- introduces contemporary research in the classroom
- focuses on 'scientific literacy', thereby focusing not only on content but also on attitudes and skills

In table 1 the major topics of the new chemistry curriculum are indicated, in table 2 an indication of the competencies is presented. Apart from these competences students should learn aspects of the Nature of Science, including doing research, designing and the use of models.

Table 1. Major topics of the new chemistry curriculum for pre-university chemistry education (unpublished material SLO)

Core concepts	concepts	Short description
Matter	Models	A model that explains the structure of matter
	Chemical bonds	All electromagnetic interaction between particles
	Intrinsic properties	Properties that can be used to recognize matter (includes things like hydrophilic/ hydrophobic, acid/base properties etc.)
	Mass	Defines the amount of matter
Scale/ proportion/ amounts	Chemical calculations	Stoichiometry, pH, ppm, excess
	Energy calculations	Enthalpy of formation
	Chemical analysis	Techniques used to acquire qualitative and quantitative data
Reactivity	Chemical processes	All types of reactions but also cycles, like carbon cycle
	Design principles	Life cycle analysis, cradle to cradle
	Production processes	Chemical technology
	Chemical equilibrium	Includes le Chatelier's principle
	Kinetics	
	Reaction mechanisms	Includes simple organic chemistry
	Safety	Safety regulations when working in the lab
Energy	Energy change	Converting energy from one form into the other
	First law of thermodynamics	
Systems	Sustainability	
	Structure/ property relationships	Different structures in matter, proteins/ different grids/ polymers

Table 2. Core competencies in the new curriculum

Acquiring chemical knowledge	Using experiments and other research techniques and models to acquire new knowledge
Communicating about chemistry	Acquire information from different sources and exchange information at different levels, using and understanding chemical terminology
Developing chemical knowledge	Using and relating chemical phenomena, concepts, patterns, laws to problems
Using and valuing chemical knowledge	Recognizing and using chemical knowledge in opinions about societal issues

The Development of the Chemistry Curriculum

In 1998 teachers did not really participate in the development of the curriculum. One of the conclusions of the van Koten committee was that it was essential to have the curriculum developed bottom-up. Teachers would identify themselves that way more with the new curriculum. Enough time was taken in order to involve the teachers in the development processes. The new chemistry curriculum was developed over a period of 10 years. As no educational material was available, this material was developed by groups of teachers, working in close cooperation with educational experts connected to teacher training at a university (‘community of learners’). The results of these experiments were discussed regularly in regional conferences where a majority of the teachers were present.

Few principles were decided beforehand as starting points for the work with the new curriculum. Apart from the principles mentioned above (context oriented, micro-macro etc.) a certain pedagogy was decided upon.

Chemistry in Context

In pedagogy Kansanen [5] introduced the didactic triangle (figure 1). The didactic triangle discusses the need for novice teachers to learn not only scientific content, but also the way they can guide the learning process of the student. In the triangle this relationship is depicted. At the center of the triangle is pedagogical content knowledge, which is basically the knowledge needed to teach a certain content. Mahaffy [6] coined the term 'tetrahedral' chemistry education, by introducing a third dimension to the triangle. He called the third dimension the human element. We called that third dimension the context. Here context "is essentially conceived in terms of a socio-cultural setting, calling for tool-mediated actions, operations, and goals that are to be valued in the framework of that activity'[7, p.481].

We have defined a context to be an authentic situation in daily life involving chemistry. Context can also be placed in an industrial setting or a research setting, as long as the situation is authentic.

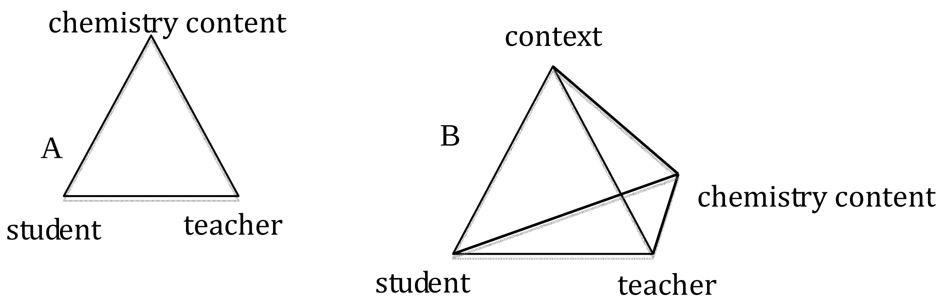


Figure 1. The schematic representation of the didactical triangle (A) and the Tetrahedral chemistry education (B)

Pedagogy in 'Chemie im Kontext' (CHIK)

In order to formulate a curriculum educational material was developed by the Community of Learners. This material was organized in modules that took in time about 12 lessons each. In table 3 the modules used in one group of teachers are given, identified by the context they started out with.

Table 3. Titles of modules used in a pre-university school.

Period	10th grade	11th grade	12th grade (final year)
1	Perfume (esters, alkenes and alcohols)	Sweetener (stereochemistry, biotechnology, peptides)	Chemistry in the mouth (pH, receptors, crystal structure of enamel, filling materials)
2	Growing (salts and pesticides)	Green Chemistry	Gasification (technology, fuels, storage of CO_2)
3	Eco travel (chemical calculations)	Energy to go (redox)	Extra module
4	Medicine (influence of pH on properties of organic compounds)	Smart materials, new materials, playing a role in solar cells	Training for final exam
5	Nobel prize (atomic models and Periodic Table.)	Sport en chemistry, (polymers and biological energy	
		Antibiotics	

The modules produced were at first based on the pedagogical model introduced by ‘Chemie im Kontext’ developed at the University of Oldenburg and IPN in Kiel [8]. In this context-oriented program four phases can be determined, in which different sides of the tetrahedron are facing forward. In the preliminary phase, in which the module is designed, the side with teacher, context and chemistry content is facing forward. (See figure 2.)

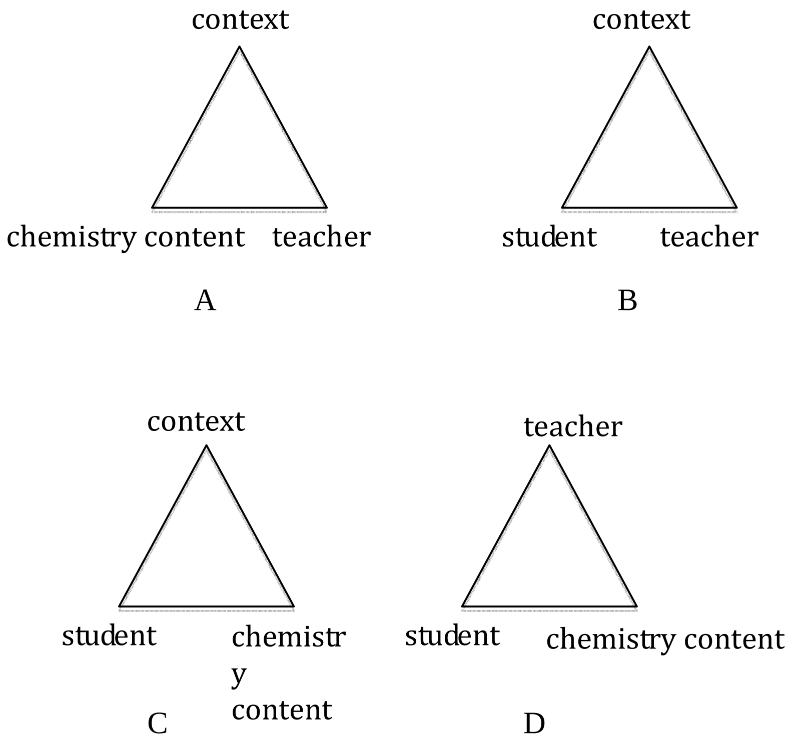


Figure 2. The different phases (A, B, C and D) of the development and execution of a teaching module in Chemie im Kontext.

In the first phase of teaching, the Introduction phase the side with the teacher, context, and student is facing forward. In this phase the context is introduced. In the second phase, called the curiosity or planning phase, the student is studying the chemistry within the context (Figure 2C). In the third phase the elaboration phase, the teacher and student are working on the chemistry determined in the second phase to answer the questions posed in phase 2 (Figure 2D). In the last phase the contemplation phase the chemistry learned in phase 3 is scaffolded and linked to existing knowledge (figure 2D).

The teachers were completely free in choosing the context and the chemistry involved. One of the changes that occurred was that subjects in chemistry were included in one module, that were previously presented in different chapters in a regular chemistry textbook. For example in the module ‘chemistry of the mouth’ subjects are biochemical in nature, dealing with taste receptors in the tongue, it dealt with acid/ base theory, discussing the buffer system in saliva as well as the polymers used by a dentist while filling cavities. This was a completely new aspect for both teachers and students.

The 5 E Model

In later modules, the teachers wanted to have slightly different steps in the module. They were not completely satisfied with the phases in CHIK. With the 5 E Model they had more time for instruction in the Explain phase. In CHIK there was little room for using the newly learned knowledge in a different context. In the 5 E Model this is made more explicit. Teachers found this to be an essential step in the learning process of the students. Because of that a change was made towards the 5 E model proposed by Bybee, Powell, & Towbridge [9] in which the steps are called slightly different (see table 4)

Table 4. Steps in the 5 E model

Engage	Introducing the context
Explore	Deriving the chemical content and formulating questions to be answered
Explain	Finding the chemical knowledge needed to answer the questions
Elaborate	Scaffolding the knowledge and determining where it might also be used
Evaluate	Evaluate what was learned (taking tests) evaluating the process, determining next subject / context to be studied

Community of Learners

This bottom-up process of developing a curriculum was deemed very important both by teachers as well as the steering committee, which led the curriculum change [10]. In order to develop modules for the whole three-year curriculum, so-called ‘Communities of Learners’ were formed, in which 5 to 10 teachers worked together with an educational expert, usually from the teacher training department of the university, a research expert and someone from industry. These 'Community of Learners' were extremely successful. At the University of Groningen (the Netherlands) the author worked with a group of teachers that developed more than 10 modules that were used and tried out within the schools. [11].

Steps in development

We organized the meetings of the Community of Learners (CoL) on Fridays afternoon. They were held about once a month and took about three hours. Schools were asked to give the teachers 54 hours off in order to participate in these CoL's. In a later stage sometimes schools were paid compensation to give their teachers time to participate. In principle it was voluntary both on the side of the teachers as well as the schools. Main argument for both teachers and schools to participate in a school was the professionalization of the teacher that took place by participating in the CoL. The modules also had a positive effect on the students.

The development of a module, including the try-out in the own school took about a year and an half. When starting to develop a module the Community of Learners takes a number of steps. It starts out with a number of brainstorm sessions about the chosen context, in which all participants, including researchers and people from industry work together. Part of the brainstorm session may include a visit to research labs or an industrial site. The chemical content is then decided upon. Then, the teachers and educational expert decide on the pedagogical format. Normally the 5 E model would be chosen. Teachers then develop and collect material that can be used in the different phases of the teaching module. In these phases of the 5 E model principles of inquiry based learning and cooperative learning are used. Students are stimulated to become active during the process.

When the material is more or less complete the researchers and industrial specialist give feedback, after which the material may be redesigned before it is carried out by the teachers in their own classes. Based on these experiences, the module is evaluated and improved. The second version is made available to other schools (see www.nieuwescheikunde.nl).

Continuous Development

The experience with working with groups of teachers working together this way was recognized was taken further in recent years. At a number of universities these groups were already active in chemistry, physics and biology. At this stage at 10 universities in the Netherlands so called ‘broad support groups’ were founded, in which these three subjects worked together. The groups were expanded with groups teaching mathematics, computer science and a subject called ‘general science’. A grant from the government made sure these groups will stay at least until 2016 (see www.bredesteunpunten.nl). These groups now play a major role in supporting the introduction of the new science curriculum. Not only chemistry has undergone this major revision, biology and physics went through the same processes.

An example of a module of the new chemistry curriculum: ‘Perfume’

The module ‘perfume’ is a nice example to demonstrate the context-concept and the different steps of the way the 5 E model works. The chemical content of the module ‘perfume’ is the introduction of simple organic chemistry. It also introduces lab work in organic chemistry using micro scale chemistry kits (Figure 3).

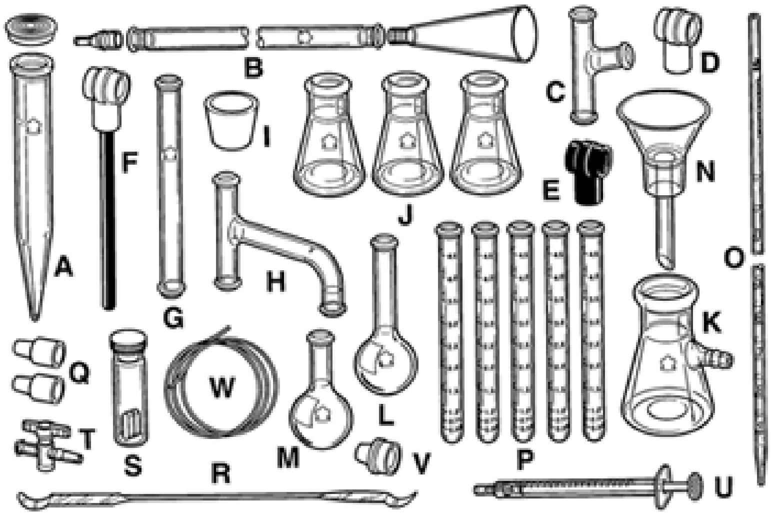


Figure 3. The Kontes Williamson microscale glassware kits(Sigma-Aldrich)

In the **'Engage'** step we have used the application for android and iphone 'Molecular City' which was developed for a science festival organized in the city of Groningen (the Netherlands) where markers were placed in shop windows (figure 4).

Figure 4. Image of molecule caffeine

When the app was loaded and the camera of the smart phone recognized the marker, a 3D image of a molecule was displayed over the camera view (figure 4). At the same time an audio message was played. For example, for the molecule caffeine the text would be: 'you keep me awake. In the app, information was given about the molecule (figure 5).

Caffeine
Caffeine is the stimulating substance in coffee, Red Bull, but also tea. One gram of tea contains even more caffeine than one gram of coffee. However, to make a pot of tea only 4 grams is used and for a pot of coffee more than 80 grams, so a cup of coffee contains a lot more caffeine. Caffeine is addictive. Moreover, you get used to it; you need more to reach the same effect. An overdose of caffeine results in all kinds of side effects, such as sweating, trembling, nervousness, fear, etc.

Caffeine is often added to painkillers like aspirin, not only because it is a stimulant, but also because it increases the effect.

Figure 5. Text for badgepage caffein

In table 4 the chosen molecules are indicated. There are English, German and Dutch versions of the app. A booklet with a description, including all markers is available on www.molecularcity.nl. Figure 6 depicts the marker for caffeine.

Table 4. Molecules used in the app ‘molecular city’ and the location where the markers were placed in the city

Molecule	**Location**
Caffeine	Café
Aspirin	Apothecary
Ethanol	One of the bars in the vicinity
Bombykol (pheromone)	Perfumery
Bucky ball	Sporting goods shop
Testosterone	Erotic goods shop
Iron	Train station
Water	Water bottle
Sugar	Ice cream parlor
Carbon dioxide	Parking garage
Vitamin C	Vegetable store/ fruit market
Cellulose	Tree
Urea	Public toilets
Lead chromate	Museum
Diamond	Jewelry shop
Capsaicin	Waga wama (awok restaurant)
Allyl methyl sulfide (garlic)	Restaurant
Cellulose nitrate (celluloid)	Movie theater
Nicotine	Tobacco shop
Methane	Gas lighter

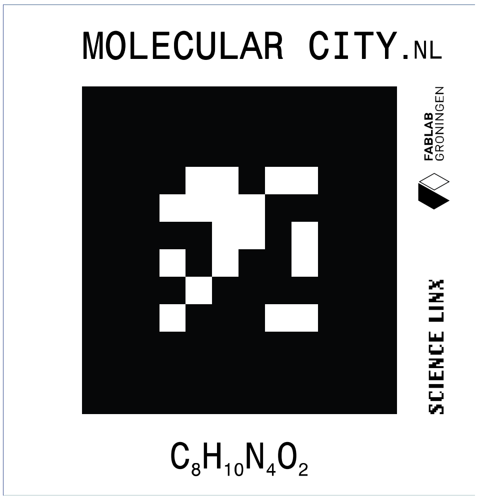


Figure 6. marker for caffein

Students usually work in groups of two or three in the modules. In the module ‘Perfume’ the app is used to introduce the molecules used in organic chemistry (Table 4). The teacher copies the markers and hangs them on appropriate places in the school. Students use their smart phone or pad to find the molecules on the markers.

Afterwards in the **Explore phase** they try to sort the molecules. They recognize similar functional groups. The idea is that students identify several functional groups in the molecules, like alcohols, esters, ketones, double bonds etc. There are also a few polymers.

In the **Explain phase** the teacher then introduces the students to the IUPAC rules for naming organic compounds. They practice and work with these rules so they can recognize simple functional groups within molecules. The students should understand that they now can name simple molecules, but that in nature molecules are a bit more complex. To conclude this phase the group of students received the assignment to design and make a concrete model of one of the molecules (Table 4) and to prepare a short paper listing properties of the molecule.

The concrete models of the molecules needed to be large enough so they could be displayed in an exhibition. The students came up with many interesting ideas to make the molecules. The molecule ethanol for example was made from (empty) cans that contained light alcoholic beverages that are favorite among these students. In figure 9 you can see the sign that was designed, as an explanation for the model the students made of caffeine. In figure 10 you can see part of the exhibition, showing the molecules bombykol, methane, and caffeine.

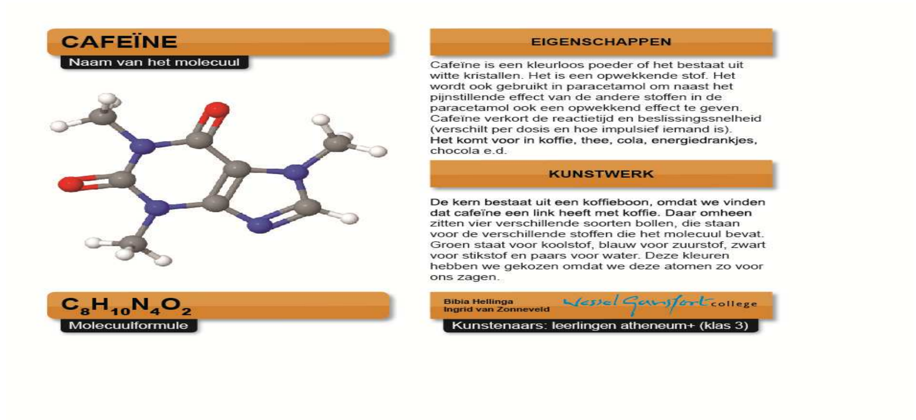
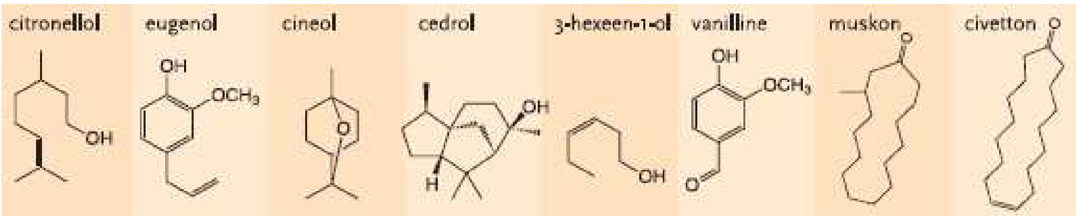


Figure 7. sign for molecules

Figure 8. Part of the students exhibition of molecules. Shown are: bombykol (top) bottom left to right: ethanol, vitamin C, Methane and caffeine.

In the **Elaborate phase** a new context ‘smell’ is introduced with a new set of molecules: Ethyl-2-methyl-butyrate; ethyl butyrate; furaneol; γ-decalacton; cis-3-hexenol. These molecules are presented to the students as about 2% solutions in 50% ethanol. The idea is that they can smell the compounds. Surprisingly, when the five compounds are smelled together you get the smell of strawberries. This leads to a discussion about smell.

Again a different number of examples are given to the students. These five were the first. Then they receive an article about smell [12]. In this article smell is discussed and explained. Properties of molecules that play a role in smell are discussed. A number of examples of these molecules are given in figure 9.



The basic idea that needs to be understood by the students is that although they learn how to name smaller molecules, molecules in the environment are generally more complicated. But they should be able to recognize functional groups within these complicated molecules. That is also the reason these molecules are used in several experiments.

Practical Skills

Eugenol and vanillin are used by the students to demonstrate the chemistry of a double bond by adding iodine to the substances. Citronellol and eugenol are used to distinguish between a primary and secondary alcohol.

Normally students will receive detailed instruction about an experiment they need to perform. In this practical, they were asked to perform a steam distillation based on an article about steam distillation and isolation of carvone [13]. Students have to derive and design their own setup, based on the article. In figure 10, an example of a setup made by students is shown.

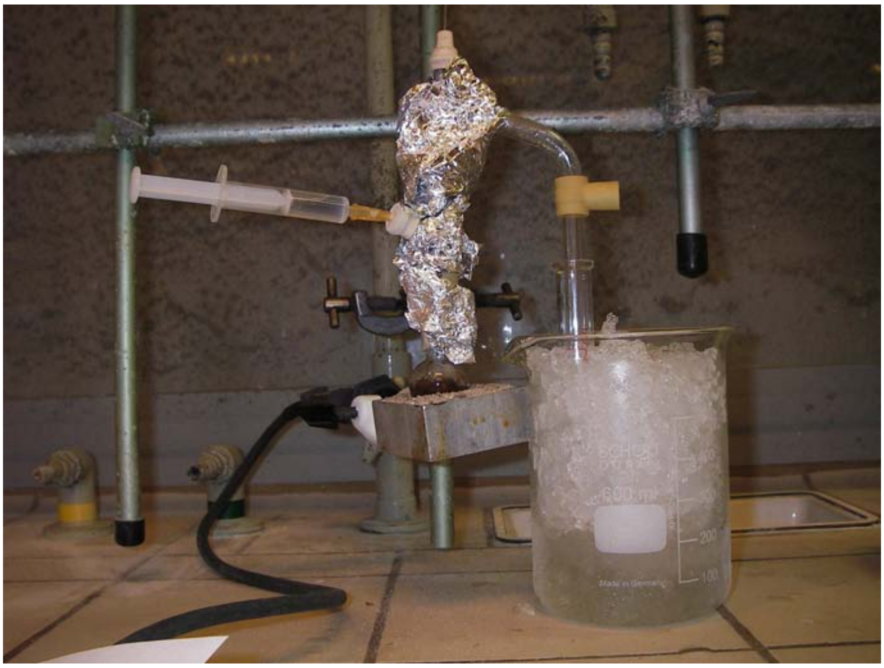


Figure 10. An example of an experimental setup for steamdestillation made by students using the Kontes set

The students are also asked to synthesize an ester. Students can choose their own acid and their own alcohol. The most favorite was ethyl butyrate, because of the smell difference going from smelly feet to pine apple.

In the **evaluation phase** the teacher helps the students to make an overview about the chemistry concepts they have learned. At the end of the module students take a final (summative and cognitive) test.

COMPLETE CURRICULUM

Using these types of modules a complete three-year curriculum was developed. In Table 6 this curriculum is described as a complete list of the modules used in three years. The different groups of teachers used different modules. Table 6 gives the modules used at the University of Groningen. The complete set of modules was the base for the description of the whole curriculum in a final exam program [14]. In the Netherlands secondary school students take a nationally organized central examination in May each year. The curriculum used for the central examination in chemistry was described using the modules developed in the different CoL.

Table 6. Modules developed at the University of Groningen

Module	**Context**	**Concepts**
1. Perfume, grade 10	smell	Introduction organic chemistry
2. Growth grade 10	What is fertilizer?	Salts, solubility, pesticides
3. eco travel grade 10	Design your own ecological trip around the world	Chemical calculations, stoichiometry
4. medicines grade 10	Why are there different ways to administer medicines	Hydrophobic/ hydrophilic molecules, equilibrium, acid/ base
5. Nobel prize grade 10	Who wins the Nobel prize for his contribution to knowledge about the atomic model?	Atomic models of Dalton, Rutherford en Bohr, the periodic table
6. artificial sweeteners grade 10	Which substances taste sweet	Chirality, carbohydrates, peptide bond, amino acids carbohydrates?
7. energy to go grade 10	How can produce electrical energy using a chemical reaction	Redox and batteries, corrosion
8. Smart materials grade 10	Solar cells, special polymers	Polymers used in solar cells, conducting polymers
9. Sport and chemistry grade 10	Materials used in sport, drinks, biochemistry of training	Krebs cycle, polymers, elasticity
10. green chemistry grade 10	Production of TiO2 and adipic acid	Industrial processes, energy balance, mass balance
11. Chemistry in the mouth grade 11	What chemistry takes place in your mouth	Buffers, receptors and polymers used in dentistry, pH-optimum of amylase
12. gasification grade 11	What is special about a power plant using gasification	Design concepts, processes and temperature, yield, sustainability, role carbondioxide

Overview

I was asked to write this article as a lecture on chemistry education in the `Netherlands, after a presentation I gave at the first African Conference on Chemistry Education (ACRICE-1) held in Addis Ababa/Ethiopia in December 2013. I have tried to sketch the background against which the changes in chemistry education in the upper level of secondary schools during the last 15 years have taken place. These changes have resulted in a new chemistry curriculum consisting of several context-concepts based modules. One publisher was willing to edit the available modules on the web. These modules are freely available for both students and teachers on http://www.vo-content.nl/stercollectie/scheikunde. A limited number of modules has been translated in English and are also available:

- http://www.studioscheikunde.nl/havovwo_bb/Module_Equilibrium/index.html
- http://www.studioscheikunde.nl/havovwo_bb/Module_Green%20Chemistry/index.html
- http://www.studioscheikunde.nl/havovwo_bb/Module_How can we eat healthily/index.html

In May 2015 the first national examination based on the new curriculum will take place. That will be the time we can see a bit more of the results of the new chemistry curriculum.

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