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The use of authentic practices as a leading principle for the design of chemistry curricula

L'ús de pràctiques autèntiques com a principi clau per al disseny de currículums de química

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abstract

The content of the chemistry curriculum has not been changed in the past seventy years. As a result, students perceive that school chemistry is not well connected to their lived worlds. We used authentic practices as contexts to select, specify, replace and/or modify specific chemistry content. This paper describes the design-based research procedure we followed to develop new sketches for a curriculum and to design an instructional framework together with exemplary curriculum units. The framework and the units were adapted as a result of several cycles of experimentation.

keywords

Authentic practices, context, design-based research procedure, exemplary curriculum units.

resum

El contingut del currículum de química no s'ha modificat en els últims setanta anys. Com a resultat, els estudiants perceben que la química escolar no està ben relacionada amb les seves vides. Hem utilitzat pràctiques autèntiques com a contextos per seleccionar, especificar, reemplaçar i/o modificar continguts químics específics. En aquest article es descriu el procediment de recerca basat en el disseny que hem seguit per desenvolupar nous esbossos per a un currículum i per dissenyar un marc d'ensenyament juntament amb unitats curriculars exemplificadores. El marc i les unitats es van adaptar com a resultat de diversos cicles d'experimentació.

paraules clau

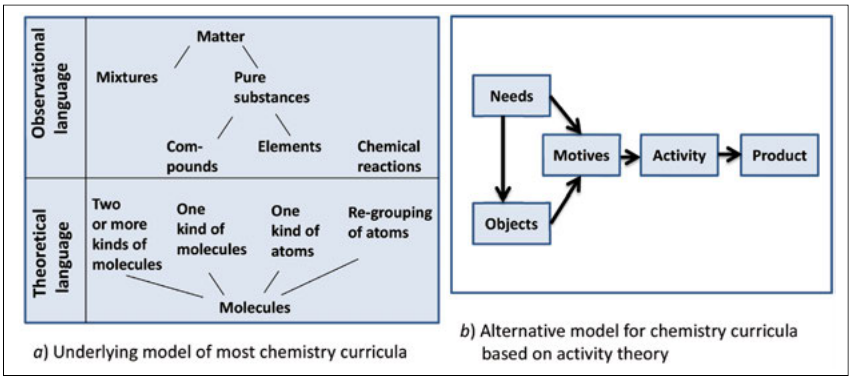
Pràctiques autèntiques, context, procés de recerca basat en el disseny, unitats didàctiques exemplars.

Curriculum renewal: what rationale for selecting content?

Whilst approaches towards education have changed during several waves of curriculum innovation in the past seventy years (Van den Akker, 1998), the contents of the chemistry curriculum during these waves of curriculum innovation have not been questioned. These waves followed each other, more or less in a rather unconscious process in which many stakeholders acted and reacted. The *Sputnik* shock at the end of the 1950s resulted in an enormous effort to improve science education throughout the US and Europe. The effort to turn the curricula into a high quality set of core concepts in relation to the learning how to set up experiments using these concepts was followed by a movement of the 1970s to make education accessible to larger groups in our democratic societies. This effort promoted that education should become less authoritarian and include new teaching methods, particularly hands-on practical work. In the 1980s, discussion started to connect secondary education and next steps in the students' learning careers. A major focus here was that students should develop meta-cognitive skills to empower their self-directed learning. At the end of the last century, most of the countries in the Western world, from the US to Europe, Japan and Australia, found their school science curricula to be boring and not interesting to students who were disinclined to pursue careers in the sciences (*cf.* Osborne & Collins, 2001; Gilbert, 2006; Sjøberg & Schreiner, 2010). In response, the «context-based» movement started in the 1990s to allow students to make their learning meaningful, connected to the world they live in, and less abstract.

Across the different waves of curriculum innovation and the problems that should be addressed, De Vos, Bulte & Pilot (2002) showed that the content of chemistry education has become self-evident. Van Berkel, De Vos & Pilot (2000) showed that the focus on «how» to use the chemistry content rarely resulted in a discussion about the chemistry content itself. The curriculum content has become the accumulation of chemistry content during the first half of the 20th century. Since then, the structure of the curriculum has hindered the accommodation of new knowledge and contemporary content. Van Aalsvoort (2000) and Van Aalsvoort (2004) analysed the underlying structure of the content of the curriculum and, in doing so, she realised that an alternative view was necessary to permit an escape from what has become self-evident (Van Aalsvoort, 2000, p. 32 and 171-174).

Fig. 1*a* represents the underlying model of most chemistry curricula. On first glance, the reader may think: what is wrong with the model as depicted in fig. 1*a*? It is conceptually clear, guiding the students' and teachers' thinking and it is a lean model, reducing the complexity of a body of knowledge as we have it in chemistry. The problem, however, is that it hinders the implementation of all new and interesting developments to be dealt with in initial chemistry education. This may involve such content as biochemistry with the development of new medication, the understanding of new diseases, nanotechnology with products in consumer products, and material science heavily applied in sports items. These new developments may induce the students' excitement; this «new chemistry» usually is product-oriented (Talanquer, 2013). A curriculum model that requires that all basics should come first avoids that new developments in chemistry can only reach students when the «simple stuff» has been dealt with, that is, polymer chemistry can only be taught «after» basic organic chemistry, and biochemistry can only be taught «after» basic polymer chemistry. How does a curriculum motivate students to pursue a career in the sciences, and in chemistry particularly, when the excitement about contemporary chemical developments perhaps never arrives in chemistry lessons? This is exacerbated when the mechanism of curriculum overload plays a part, with the result that «the most difficult stuff» is left out of the curriculum in favour of teaching «the basic material».



a) Underlying model of most chemistry curricula
b) Alternative model for chemistry curricula based on activity theory

Figure 1. Conventional and alternative model for the chemistry curriculum (Van Aalsvoort, 2000).

It therefore may be worth considering an alternative leading principle and exploring the possibilities that it opens. The point is not to reject the model in fig. 1*a*. It still is useful to consider content. The difference, however, is not to use it «as a leading principle to construct» a curriculum (Van Aalsvoort, 2000, p. 180). For this purpose, Van Aalsvoort adopted a cultural-historical approach. Taking Leontiev's ideas concerning activity theory as a guide, she analysed the «needs» of a society (fig. 1*b*), needs that should result in a specific object, in terms of chemistry usually a product, such as a new medicine. The society has motives for wanting this object (product) and consequently develops activities to produce it. This is how a certain social practice develops within a particular cultural environment. Connected to the social practice is (chemistry) knowledge; it is «secondary in the sense that knowing as an activity is primary» (Van Aalsvoort, 2000, p. 180). A society knows the interplay between different practices, and as our societies are highly complex, a division of labour has taken place.

At this point, we first need to be explicit about the definition of an *authentic social practice*. The term *authentic* is used to indicate that there is a real, authentic, activity in society. The chemical activity exists in the real world; it is not an artificial; «real» people somewhere in the society enact in it. The characteristics of one practice are typified by Prins *et al.* (2008): *a*) common motives for dealing with the issues of the real societal activity; *b*) common conceptual (chemistry) knowledge that the participants of the activity share, and *c*) common procedural knowledge, as shared procedures are operational to address the issues of the activity. Different practices exist, such as the professional activities of, for example, a dentist who uses dental products, consumers who go to a dentist, producers of dental products, technicians who analyse these products or chemists who carry out research to improve the products. Chemistry-related products (most products!) involve many different «types of practices», and the participants of the society can have «different roles», as professional, as researcher, as consumer, as lab analyst, etc.

The idea of using authentic practices as input for constructing chemistry education may be a route to explore whether the challenges of chemistry (science) education can be addressed (*cf.* Pilot & Bulte, 2006). First, the social practice defines the choice and depth of the concepts that are operational. Content overload still may be a pitfall; however, if the curriculum designer keeps the social practice as the leading principle, overload may be avoided. Ideally, the «need-to-know» is guided by the issue of the practice. This need-to-know should guide students in how to «connect» the knowledge used. Dealing with an issue of using and developing a certain set of chemistry knowledge should «integrate» this knowledge, which is «relevant» to the practice.

How, then, can the model of activity theory be used as a leading principle for chemistry curricula, since this requires the selection of certain practices with certain criteria in mind? Instead of the difficulty of selecting content, we now face the difficulty of selecting practices that are suitable for educational purposes. Additionally, in the process of sequencing practices during the course of the curriculum, the practices should be such that each of the practices lies in the zone of proximal development for students with certain ability and a certain age (Sevian *et al.*, 2014, p. 302). Construction of curricula based on social practices implies a two-dimensional design process comprised of sequencing in practices with increasing levels of complexity, mimicking different types of social practices (Sevian & Bulte, 2015, p. 63-75). As a consequence of the increased complexity of the social practice, a certain set of chemical concepts will come to the fore. Both the complexity of the practice and the complexity of the concepts should be in line with what is in the students' zones of proximal development. The selection of practices themselves is not the only exploration that needs to take place. It is a challenge in itself to transform an authentic social practice into a curriculum unit for the purpose of learning chemistry. What is «authentic» as a practice in society is not necessarily accessible as «authentic» in the learning process of students. In the next section, we first address the exploration of the idea of using social practices for the construction of a curriculum. Subsequently, we explore the possibilities of social practices for the construction of a curriculum unit.

An exploration of the concepts of *matter*: the level of the curriculum

This exploration has been extensively described in Sevian & Bulte (2015) for the concepts of *matter*. The input for this exploration is provided by the studies of Meijer, Bulte & Pilot (2009); Meijer, Bulte & Pilot (2013); Sevian *et al.* (2014), and the studies on learning progressions by Wiser, Frazier & Fox (2013). Here we provide a brief overview. Fig. 2 illustrates part of a summary of how a chemistry curriculum (*e.g.* ages 8 to 18) could roughly be outlined, based on the notion of a consistent choice for one (authentic) chemical practice for one teaching unit. In offering this example, we intend to suggest broad guidelines for what types of practices, and in what sequence, would be appropriate for different ages of students.

Matter; structure & property (could also be on energy)

Type of practice				*(Exemplars) Concepts*	*For whom?*
Producing	*Food-1*	*Food-2*	*Goods, etc.*	**«Stuff» Objects, materials, ingredients**	Primary
Evaluating quality	*(Drinking) water*	*Food-3*	*Goods (e.g. in mining)*	**«Quality» in terms of components: substances; elements**	Lower secondary
Conceptual designing (synthesis)	*Food components*	*Drugs*	*Electronic devices*	**«Buildings blocks» meso-levels & molecules; atoms**	Upper secondary
Researching / inquiry	*Food & health*		*Nano*	**«Modelling» as the product of doing science**	

Figure 2. A sketch of a curriculum outline with a sequence in units (horizontally) and a sequence in type of activity (vertically), each leading to a need-to-know for a set of chemistry knowledge (Sevian & Bulte, 2015).

The first column of the table shows types of practices as proposed by Sevian & Talanquer (2014). Here they are sequenced as producing > evaluating > designing > researching.

For example, the first cell shows a theme of food with an activity of producing, and together these comprise a practice of figuring out what something is made of. Examples of these practices are the production of food or drinking water, the evaluation of the quality of drinking water or a food component, or the conceptual design of a new medicine. In each row connected to a specific activity (*e.g.* producing), then, different themes can be chosen. Each cell's theme (*e.g.* drinking water) is a lead theme for one teaching unit. The whole set of themes (very likely to be more than the three examples shown in fig. 2) within one row should then gradually build up the intended chemical ideas which should match with students' interests and students' abilities, for example for one year, or one specific period of chemistry teaching. At the end of each of the rows, the curriculum could be designed to have students experience the need for a next type of activity. This brings students from the less complex activity «producing» to a more elaborate activity «evaluating», etc. The idea is that producing and dealing with objects and materials around them is in each student's zone of proximal development when starting their chemistry or science education, whilst thinking about the quality may bridge too far in the beginning, but lies within the zone of proximal development after several teaching units about producing. This learning process should result in then there should be an affective «stepping stone» to think about the evaluation of the quality of products.

It is essential to restrict the concepts that are operational within each unit to those necessary to address the issue/topic of the unit. This is to avoid mechanisms that bring so-called *self-evident* content to the drawing table, and thus fall into the pitfall of overloading the curriculum. Fig. 2 shows that certain social practices allow new concepts of at least a new focus on content. For example, «quality» practices give a focus on the chemical background on how *quality* could be determined chemically: certain components with a certain concentration are allowed in a product. Another example is a stronger focus on material science in which knowledge about micro- and meso-structure is important (Meijer, Bulte & Pilot, 2009; Meijer, Bulte & Pilot, 2013). It is essential to maintain a meaningful «storyline» within and between the several units.

An exploration at the level of a curriculum unit

This section deals with the question: how to balance authenticity of a practice (complex) and the (reduction of) complexity? We will illustrate how we have explored this question with a curriculum unit on learning of modelling in chemistry education (Prins *et al.*, 2008; Prins *et al.*, 2009; Prins, Bulte & Pilot, 2011; Prins, Bulte & Pilot, 2016; Prins, Bulte & Pilot, 2017), since this example illustrate the successive stages of research. Other examples are described elsewhere (Bulte *et al.*, 2006; Westbroek *et al.*, 2010; Meijer *et al.*, 2013; Van Aalsvoort, 2004; Dierdorp *et al.*, 2011).

We have worked according to a design-based research approach using the following stages:

A) We started with a long list of modelling practices as possible candidates for use in chemistry education. Possible modelling topics were evaluated using the following criteria: students' interest, complexity, familiarity and possibilities for laboratory work. This long list resulted in the selection of a short list of social practices as possible candidates (Prins *et al.*, 2008).

B) The practices of the short list were analysed in more detail; additionally, we interviewed experts in the field (Prins *et al.*, 2008). These analyses resulted in a fine-grained knowledge of each of the three social practices described in terms of common issues, com-

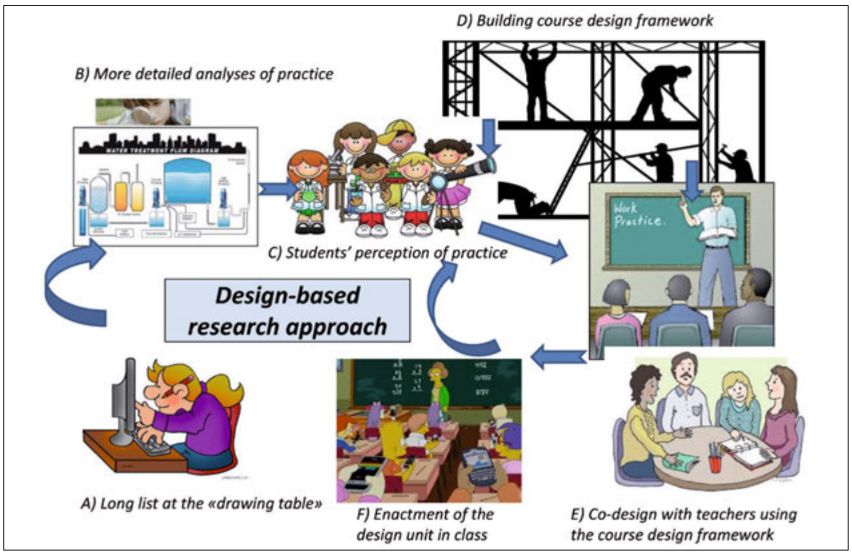


Figure 3. The stages A to F in a design-based research approach, in this case on the transformation of authentic social practices into a curriculum unit for the learning of chemistry.

mon knowledge and common procedures. Eventually, two of the three practices remained: modelling of drinking water treatment and human exposure assessment.

C) The first stages of the two curriculum units were designed. This means that the starting activities of the unit could be tested with students. Subsequently, we held a focus group interview with the students to evaluate whether the practices appealed to students (Prins *et al.*, 2009). We concluded that both practices were suitable for further elaboration.

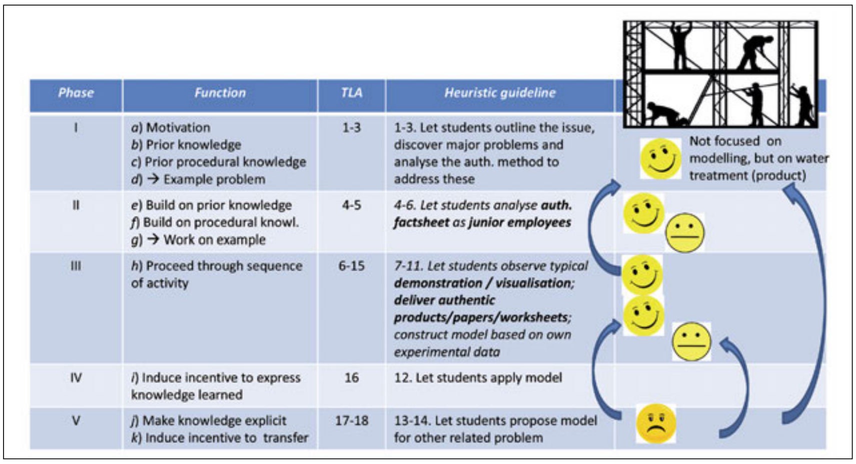
D) In the design process, we made use of an explicit course design framework. Such an instructional framework consists of three basic components (Prins, Bulte & Pilot, 2016):

1. The learning trajectory is divided into distinct phases with explicit modes of learning, such as orienting, planning or reflecting.
2. Each phase consists of design guidelines.
3. Each learning phase holds a number of pedagogical functions (fig. 4-5).

E) The unit on modelling drinking water treatment was co-constructed with six teachers (and two science educators, the first and second authors). This design team could build on the detailed analysis of the authentic social practices and made use of the explicit course design framework. We reconstructed the heuristic guidelines for design from the design process.

F) The unit was tested in classrooms and revised in several cycles (stages D, E and F; see Prins, Bulte & Pilot, 2011; Prins, Bulte & Pilot, 2016). Adaptations could also lead to a reformulation of guidelines for design.

In the authentic practice, the experts sought to represent the complete water treatment process using a series of mathematical models that enable the prediction of the quality of drinking water after various treatments (Prins *et al.*, 2008; Prins, Bulte & Pilot, 2016). The curriculum unit focussed on one of the treatment steps, that is coagulation and flocculation. This is a concrete step to remove turbidity that is influenced by different parameters. The unit was enacted in class by six teachers with students in grade 10/11 (aged 16-17).



Phase	Function	TLA	Heuristic guideline	
I	*a)* Motivation *b)* Prior knowledge *c)* Prior procedural knowledge *d)* → Example problem	1-3	1-3. Let students outline the issue, discover major problems and analyse the auth. method to address these	Not focused on modelling, but on water treatment (product)
II	*e)* Build on prior knowledge *f)* Build on procedural knowl. *g)* → Work on example	4-5	*4-6. Let students analyse* ***auth. factsheet*** *as* ***junior employees***	
III	*h)* Proceed through sequence of activity	6-15	*7-11. Let students observe typical* ***demonstration / visualisation; deliver authentic products/papers/worksheets;*** *construct model based on own experimental data*	
IV	*i)* Induce incentive to express knowledge learned	16	12. Let students apply model	
V	*j)* Make knowledge explicit *k)* Induce incentive to transfer	17-18	13-14. Let students propose model for other related problem	

Figure 4. The course design framework for a unit with the learning phases I to V, each with specific functions, teaching and learning activities (TLA) and heuristic guidelines for transformation of the authentic practice into the unit (in bold: those guidelines that are changed as a response to the evaluation). The results of the evaluation are summarized symbolically; for details of this first cycle, see Prins, Bulte & Pilot (2016).

Fig. 4 gives the main highlights of the unit's evaluation in class. In general, the first three phases functioned well. Especially the orientation on the practice with a fact sheet of a related but similar problem gave students a clear impression what was expected. However, only after a demonstration experiment at the start of learning phase 3, did the activities become much more meaningful for the students. From then on, the students expressed more in-depth interest for the case. At the end of the unit, we found that students could not relate their learning to another example. That is, they expressed limited ability to reflect upon the modelling approach. The arrows in fig. 4 show how the parts that did not function as expected could be related.

This evaluation led to the following recommendations for the next cycle:

— In general, the outline of phase 1 and 2 was maintained, using the pre-structured fact sheet as an organiser.

— The demo experiment was planned directly in phase 1.

— There was less focus on the explicit student roles.

— An additional orientation on different modelling approaches was planned in phase 1; this could be used in phase 3 and reflected upon in phase 5.

The adaptations are shown in fig. 5 with the modifications of the guidelines shown in bold.

The outcomes of the design-based research process with the detailed evaluation of the curriculum unit can be found in Prins, Bulte & Pilot (2011) and Prins, Bulte & Pilot (2016). To study the validity of the guidelines, the outcomes of this course design framework were used for the design of a second curriculum unit about human exposure assessment, for which the authentic social practice had already been analysed (Prins, Bulte & Pilot, 2017).

Learning phase	*Function*	*TLA*	*Heuristic guideline*
I. Orientation on practice	*a)* Motivation *b)* Prior knowledge *c)* Prior procedural knowledge *d)* → example problem	1-4	I-III. Issues of practice with implication to daily life ***IV. Let students observe demo & conceptualise***
II. Exemplary problem	*e)* Build on prior knowledge *f)* Build on procedural *g)* → work on example	5	V-VII. Authentic product plan
III. Solve problem	*h)* Proceed through sequence of activity	6-17	***VIII. Let students think of type of modelling approaches*** IX-XII
IV. Reflect on findings	*i) Evaluate knowledge learned* *j) Reflect on proc. Knowledge*	18-19	***XVI. Let students recall different types of modelling***
V. Knowledge learned	*k)* Make knowledge explicit	20	XVI

Figure 5. The redesigned framework and the unit of the second cycle (Prins, Bulte & Pilot, 2011; Prins, Bulte & Pilot, 2016). In bold and italics: changes compared to the previous version.

Reflection on the exploration: towards new leading principles for chemistry curricula and the construction of curriculum units

The paper describes the first exploration of the use of authentic social practices as a leading principle for curriculum design provides an alternative.
The first step is the sequencing of practice by distinguishing between the types of practices. These can be differentiated by the different verbs (to produce, to analyse, to design, etc.) in relation to chemical activities in society, with different levels of complexity. This illustrates «knowing as an activity is primary» in activity theory (Van Aalsvoort, 2000, p. 180). «After» this analysis, a two-dimensional outline may be constructed mapping the complexity and familiarity of the social practices with the complexity of the concepts using the input from studies on learning progressions. The designer can use the input of learning progressions in mind, which has been done for the concepts of *matter* here. This input is important when such a sketch is constructed for other concepts, *e.g.* the concepts of *energy* (Neumann *et al.*, 2013), although the concepts should not be leading.

At the level of curriculum units, the design process has been sketched above (stages A to F and the cycles thereof). The different heuristic guidelines for transformation are related to the following:

— The connection of the practice to the students' lived worlds and the implications for their «daily life» should be recognisable.

— A strong role identification is not effective nor necessary.

— At the start of the unit, a typical visualisation of typical issues by means of a guiding experiment is important.

— The chain of motives to proceed to a next activity is not the same for experts as for students, and should therefore be subject to study.

— Maintain a procedure as an organiser of the authentic practice that provides for a strong scaffold in the unit.

— Attention for the reflection phase is necessary: it requires an explicit orientation toward the procedure and the knowledge at the start in order to be able to reflect upon it at a later stage.

The paper gives a broad overview of a «proof of principle» using authentic practices to design the chemistry curriculum. Much is open for debate: for example, what is the usefulness of this course-design framework for the construction of other units, and what can be learned from our approach for the use of other curriculum principles and vice versa? How can units be connected for other concepts, *e.g. energy*? What criteria can be developed for the choice of social practices in different cultural environments and for different educational (learning) aims, and what are the adaptations when students are subject to a different *Zeitgeist*? At least, the approach opens up new routes for exploration and offers an alternative that avoids the self-evident choices; there is a possibility to escape.

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