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A research approach to designing chemistry education using authentic practices as contexts

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Abstract

We discuss how to reduce the incongruence between the outcomes (both cognitive and affective) of the conventional secondary chemistry curriculum and what is to be attained: the meaningful connection of students' learning to daily life and societal issues. This problem is addressed by a design study with one curriculum unit about 'Water Quality'. With several research cycles using developmental research, we developed an emergent understanding about an instructional framework for curriculum units that embodies a coherent 'need-to-know' principle and is based on authentic practices. Using this framework we show with some other examples how a context-based chemistry curriculum can be constructed on the basis of the developed 'need-to-know' principle.

Introduction

Many students experience the chemistry curriculum as abstract, difficult to learn and unrelated to the world they live in (De Vos, Bulte, & Pilot, 2002; Osborne & Collins, 2001). Context-based chemistry curricula are considered as a way to resolve these unsatisfactory outcomes of conventional school chemistry, especially with respect to the affective domain. The assumption is that recognisable contexts appeal to students and provide for a 'need-to-know' basis for the chemical concepts to be learned. Through the context, students are expected to give meaning to the chemical concepts they learn. This strategy has been followed since the 1970s and 1980s for physics (see e.g. PLON: Eijkelhof & Kortland, 1988) and chemistry education (see e.g. Salters: Campbell et al., 1994). Recently, this strategy has been promoted in Germany (ChiK: Parchmann et al., this issue) as well as in Dutch policy documents (Driessen & Meinema, 2003).

Several context-based approaches claim that through the underlying instructional framework the contexts raise questions in students and make them see the reason for extending their knowledge. Such an instructional framework therefore has to embody a 'need-to-know' principle: the context must legitimize the learning of chemical theory from the perspective of the students and thus make their learning intrinsically meaningful. However, the extent to which the 'need-to-know' principle has been implemented within curriculum units has not been established empirically (Westbroek, 2005). For example, do students indeed feel that contexts provide a meaningful 'need' for learning new chemical theory, is there a coherent flow of activities to learn this chemical theory from a student perspective? Can students indeed show why they perform their learning activities at every step within one unit? In other words, is the intended meaningfulness of the chemistry curriculum unit realised by implementing a coherent 'need-to-know' principle?

In light of the problems described for the chemistry curriculum, we decided that the investigation of the 'need-to-know' principle is a relevant research issue. We address this problem with an in-depth design study for one curriculum unit. The research objectives are as follows:

- to develop an instructional framework that embodies a coherent 'need-to-know' principle,
- to make this framework available for the analysis and further development of other units,
- and to illustrate how such an in-depth design study can contribute to an empirically based curriculum development.

Consequently, we address the following research question.

> What framework for chemistry education connects contexts to concepts on a coherent 'need-to-know' basis within one curriculum unit?

This question has been approached by taking a designed curriculum unit itself as object of our research. In contrast to common research approaches to evaluating outcomes, the chosen research focus requires an in-depth understanding of how and why enacting a certain curriculum unit lives up to its intentions or not. Our objectives therefore require a design research strategy.

Background: curriculum representations & design research of exemplar units

To make such outcomes available for curriculum development, we combine a model of curriculum representations (Van den Akker, 1998) with our approach of design research. Van den Akker (1998) describes the model of curriculum representations as follows. The ideal curriculum represents the original vision, basic philosophy, rationale or mission underlying the curriculum. In the formal representation of the curriculum this vision is elaborated in a curriculum document. The perceived curriculum gives the description of the curriculum as it is perceived by its users, especially teachers. The operational curriculum represents the actual instructional process in the classroom. The experiential curriculum described the actual learning experiences of the students, and the attained curriculum represents the resulting learning outcomes of the students. Van den Akker has argued that the typology of curriculum representations is a helpful analytical tool where there is incongruence between curriculum ideals, what takes place within the classroom, what is experienced by students and what is attained.

A curriculum design process takes place in several cycles (Figure 1a). It starts with the confrontation of an ideal (new) curriculum with what actually takes place in the current operational curriculum, the experiences of students and teachers with it, and what is attained. This analysis of curriculum problems is the first stage (i) in the first cycle. This describes the starting incongruence between ideal and the operational, experiential and attained curriculum. In our case that is the contrast between students' experiences with the abstract and distant curriculum of school chemistry and the wish to make chemistry education relevant, meaningful and based on a 'need-to-know' principle, the initial motive to develop context-based curricula. As a second stage (ii) appropriate theoretical notions are selected and combined for the transformation of the ideal curriculum to a formal representation of a newly designed exemplar curriculum unit that serves as a vehicle to develop, investigate and communicate the 'need-to-know' principle for a context-based curriculum. This design process actually takes place in a third stage (iii) with a description of the curriculum materials, the underlying framework and its operationalised 'need-to-know' principle. A fourth stage

(iv) can be described as the explicit identification of the operationalised 'need-to-know' principle within the curriculum unit, and the development of instruments to evaluate whether the planned operational, experiential and attained curriculum is in accordance with what actually takes place, is experienced and is attained. This evaluation is the fifth stage (v).

After the evaluation in the first cycle, a confrontation between ideal and the outcomes of the first cycle again takes place. This stage actually is a further step towards a 'sharper' problem analysis. The cyclic process aims to reduce the incongruence between ideal and what is implemented. But did it reduce the incongruence, what have we learned, and how can the occurring problems be better understood? This stage (i) is the start of a second cycle followed by the subsequent stages as in the first cycle: (ii) selection, combination and following from the conclusions of the first cycle also the generation of theoretical notions, (iii) description of a redesigned curriculum unit, its underlying refined framework, and design principles, (iv) identification of the operationalised design principle for evaluation, and (v) the evaluation. This developmental process continues until the incongruence has been reduced to an acceptable level.

This cyclic, or more correctly spiral-shaped, approach can be understood as 'walking down a winding staircase with five stairs' until all stages are at an acceptable 'congruent' level (Figure 1b.). This design research process aims at the following outcomes:

(i) an appropriate understanding of the (curriculum) problem

(ii) the selection, combination and (also) generation of theoretical notions to the curriculum problem

(iii) an empirically based curriculum unit and its underlying framework

(iv) insight in and understanding of the evaluation process for curriculum research, and

(v) appropriate evaluation data.

---- INSERT FIGURE 1 ABOUT HERE ----

Method

Strategy

Our approach of developmental research (Lijnse, 1995) finds its place among the family of design research in the sense that it both implies instructional designed units and analytical research of those units (Cobb, Stephan, McClain, & Gravemeijer, 2001; Lijnse, 1995). A detailed design of a teaching and learning process is accompanied with a set of argued expectations how a unit is expected to function, and why it should operate according to the expectations. This 'why' – component includes evidence from the literature as well as research findings from earlier research cycles. The selection of data, the interpretation and analysis are guided by the question to what extent the implemented unit is in accordance with the expectations. These expectations (the how and why) serve as a scheme for evaluation. Developmental research thus can be considered as a mainly top-down approach using small scale interpretative case studies. The main teaching and learning phases of a unit are followed in necessary detail according to its underlying framework. When the actual implementation of a unit differs from the expectations, a new understanding needs to be generated. Then the data analysis is directed to an emerging understanding of the learning process that did (or did not) take place. This emergent understanding, where possible interpreted in the light of literature findings and new theoretical notions, is used as new evidence in a next research cycle. A classroom with its teacher is considered as a unit of analysis (Cobb et al., 2001).

Case study: exemplar unit about 'Water Quality'

As a vehicle to develop, investigate and communicate the 'need-to-know' principle, we decided that the context of the unit would be 'water quality' (Westbroek, 2005) and specifically 'testing and judging the quality of surface water in the neighbourhood'. This choice was inspired by projects like Globe, the Evolution of Water project, Green and several others (Howland & Becker, 2002; Rivet, Singer, Schneider, Kraijick, & Marx, 2000). Water quality is a well-known rich context in chemistry (and science) education. It fits with the goal that students should learn about how chemistry or science actually functions in society, and it is expected to be appealing to students, because it affects them personally (ideal curriculum). It was our explicit intention to position this new unit at the start of chemistry education in the Netherlands with students aged 15.

Concepts such as concentration, standardised experiments to determine water quality, accuracy, reliability and validity of laboratory-experiments, all in relation with legal parameters and norms needed to be integrated within the unit in such a sequence that students experience a 'need-to-proceed' to a next activity (see Figure 2). The intended experiential curriculum for students is described as the coherent flow of activities: each activity of this curriculum unit should induce a need-to-proceed to the next activity.

---- INSERT FIGURE 2 ABOUT HERE ----

Data collection and analysis

Three research cycles took place, each at different schools with three different teachers who were especially prepared (most extensively in the third cycle) to teach each unit during the years 2001-03 in their classes. Some schools and teachers were involved in more than one cycle. In each cycle the (re)designed unit was constructed by the second author, while receiving feedback from the research team (first & last author and an additional member (KK), see acknowledgements). The curriculum materials were accompanied with the description of a set of detailed expectations (formal curriculum).

Data collection took place by videotaping the teaching and learning process, by classroom observations [second author] at moments that reflect the expectations of the phases in the framework of the curriculum unit (see Tables 1, 2 & 3 in the next section, operational curriculum), by specific student questionnaires after teaching each unit (experiential curriculum), by post-intervention interviews (experiential curriculum), and by collecting worksheets and reports of students (attained curriculum). Their learning results were investigated by means of a test that was specially designed for this purpose (attained curriculum).

Analysis and interpretation of the data were performed according to the following procedure. Video fragments at the critical instances in relation to the expectations (see above) were selected and transcribed verbatim by the second author to verify whether each phase of the framework (and the related activities) proceeded according to its expectations. Additional data from student materials, questionnaires and interviews were used as triangulation when necessary. These first qualitative descriptions were verified by a second researcher (KK) until consensus was reached about the findings. These 'thick' descriptions about the evaluation of the expectations were further discussed in the full research team and adapted when necessary. For each cycle this whole set of descriptions was used to finally answer the question: 'was the designed unit adequate for its purpose'.

The main steps in the process of developmental research are presented within the research model of Figure 1, using the intermediate stages (i → v) in each research cycle. In the evaluation (v) summaries of the 'thick description' with respect to the 'need-to-know' principle within the operational and experiential curriculum are presented mostly based on the findings of classroom observations, the analysis of students materials and the transcripts of videotapes. Besides, statements from interview transcripts and questionnaire responses are used to illustrate (and triangulate) the students' experiences evaluating to what extent after three cycles our ideals were in accordance with the operational, experiential and attained curriculum. The research instruments, analysis and interpretation are more fully described elsewhere (Westbroek, 2005).

Results: First cycle

(i) Incongruence: problem analysis

The curriculum problem is the starting point (see the previous sections 'Introduction' & 'Background').

(ii) Selection of theoretical notions

For the design of the first unit, a three-phase framework (Table 1) was used (Kjersdam & Enemark, 1994; Peters & Powell, 1999). 'Water quality' is used as a motivating context (see description of case study). The three-phased framework is comparable to the framework of the PLON-units (Eijkelhof & Kortland, 1988).

(iii) The design of the formal curriculum

A leading context-question, 'Is the water clean enough in our neighbourhood?' was introduced as the context in phase I. From this, a set of sub questions (Table 1) was derived that was expected to embody the 'need-to-know' principle as a route to an answer to the leading context-question above. These sub questions guided the actual design of activities. Phase II was expected to be connected to phase I by question 4, evoking a need for general knowledge about accuracy and reliability of colorimetric experiments. Its contents (question 5) consisted of context-independent knowledge how to visually determine the sequence of a set of test tubes with different concentrations of copper chloride solutions, and to use this calibration sequence to determine the concentration of unknown solutions (concepts of accuracy). The students were expected to apply this knowledge (questions 6 – 8) when judging quality of the water samples they had collected in their neighbourhood during phase I (question 2 – 4). Phase III was planned to end with a collective reflection on the whole process: what does it take to determine water quality?

----INSERT TABLE 1 ABOUT HERE---

(iv) The identification of the operationalised 'need-to-know'-principle

Table 1 indicates the main phases of the first framework and the expected flow of activities reflected by the subsequent sub questions of the designed unit. This operationalised set of expectations gives the following research question for the evaluation of this cycle:

> Did the three-phase framework and the sequence of sub questions induce a coherent flow of 'need-to-know': did phase I provide for a 'need-to-know' to proceed to phase II, and did the students meaningfully apply their knowledge when evaluating the quality of their water samples (phase III)?

(v) The evaluation shows that students were very motivated to answer the leading context-question [video-transcripts & classroom observations]. Just after the start (question 1), much earlier than intended, most groups of students arrived at the question, 'what should we test our water sample on?' (question 3C). The sub questions 2, 3A and 3B, their content and sometimes their sequence did not reflect what students considered as an answer to the leading question [video-transcripts, classroom observations, post-intervention interviews, and analysis of student materials]. In phase III, when they finally arrived at their conclusions (question 7) i.e. judging the quality of their water samples (in cases which anyway were much too complex), they did include the intended concepts of accuracy. The students did the section on accuracy of colorimetric methods (phase II, question 5) without complaining (much) [classroom observation]. They generally enjoyed doing the laboratory assignment to determine the sequence of a set of test tubes with different concentrations of copper chloride solutions and guessing the concentrations of the unknown solutions by using this calibration sequence as if it was some sort of competition [classroom observation]. They generally concluded fairly easily, as intended, that it 'was not a very accurate method'. None of the groups, however, included these concepts of accuracy of the outcomes of colorimetric measurements in their written and presented judgement of their water samples (question 8, phase III) [analysis of student materials & classroom observation]. Only at one point these concepts really did become meaningful [video-transcripts & classroom observations]: A group presented their findings and judgement for their classmates (question 8). They had judged their water as clean enough to swim in, although one of their test results was just below the norm. A classroom discussion emerged if you could take such a risk: because their colorimetric laboratory experiments were not so accurate, the real value of this parameter might very well exceed the norm. Only then the students did see the point of addressing the concepts of accuracy. Students only afterwards experienced that what they learned by answering this sub question had contributed to their answer to the leading context-question. None of the students [post-intervention interviews] could adequately explain why this activity (phase II, question 5) was part of the unit, what they thought it was about, what they had learned from it, let alone if and how they used what they had learned from this section in judging their water sample.

It can be concluded that the three-phase framework and its sequence of sub questions was not adequate for its purpose. It did not induce in students a coherent flow of 'need-to-know' at the moment the students were to extend their knowledge. The intended (context-independent) concepts of accuracy of measurements (phase II) only did become meaningful afterwards during the intended application of these concepts (phase III), and was not planned on a 'need-to-know' basis from the perspective of students.

Results: Second cycle

(i) Incongruence: refined problem analysis

The problem was that the sub questions, which framed the sequence of learning activities, had not emerged from the students' own experiences. Its sequence and the general knowledge involved (phase II) is considered relevant from an experts' point of view, from the perspective and the context of those who already have acquired this knowledge. This results in a more precise problem analysis: to establish through the context a coherent flow of activities following the 'need-to-know' principle from the perspective of students, that is from those who are not yet familiar with the knowledge to be acquired.

(ii) Selection of theoretical notions

The challenge is to design a unit with learning activities in such a way that it builds on the previous one and induces a need for the next learning activity, and so on. Lijnse & Klaassen (2004) refer to this 'knowledge need' as the development (with students) of a content related motive, and define this approach as problem posing. This basically means that teaching -

learning activities are designed in such a way that students are put in a position that they feel the need and see the point of extending their knowledge in a certain direction in light of their desire to answer the leading context-question. The designed learning activities should thereby make proper use of the already existing intuitive notions students have of what is involved, in this case, judging the water quality of a water sample.

(iii) The design of the formal curriculum

The design process of the second unit is inspired by a framework of this problem posing approach. Within an overall motive (corresponding with the leading context-question) a series of connected and nested content-related motives should be induced in students by using the students' intuitive knowledge of what would be the next logical step of the procedure of quality control in four phases (Table 2). In this way the students' content-related motives frame the sequence of sub questions and their related activities: a problem-posing flow of sub questions with the intended content-related motives frame an expected coherent need-to-know about the next step (Table 2).

Compared to the framework of the first unit, phase I was replaced by the new phases 1 and 2. A general orientation on judging water quality in several cases (phase 1) needs to focus on the problem (in phase 2) to direct the 'knowledge-need' more specifically onto an exemplary case. Knowledge extension in a general sense (phase II) was replaced by phase 3 in which knowledge extension takes place in light of the now more specifically defined and less complex problem. This rather fundamental change in framework also has led to a different sequence of sub questions. Students were expected to build on their intuitive notions judging water quality in different cases (question 3) to focus on the exemplary case of drinking water (question 4). Furthermore, following the evaluation of the first cycle, they were expected to experience the consequences of accuracy, reliability and validity (question 8 replaces the former questions 3 & 4) only after they had measured the quality of their water samples first (question 7).

---- INSERT TABLE 2 ABOUT HERE ----

(iv) The identification of the operationalised 'need-to-know' design principle

The new framework, its new phases and the sequence of the activities guided by the sub questions directed the evaluation of the second unit (Table 2). The operationalisation of the need-to-know principle is the induction of a context-related motive at every step of the teaching and learning sequence, leading to a set of expectations. This leads to the following research question for the evaluation in the second cycle:

> Did the four-phase problem posing framework and the sequence of sub questions induce the intended content-related motives?

(v) The evaluation shows that students were motivated by the leading context-question like in the first version (question 1) [video-transcripts, observations, interviews, student worksheets]. The quantitative motive 'what is in the water?' emerged, although the quantitative part 'how much?' was not put forward by the students (question 5, phase 3). After the students had performed their measurements, the students raised the question of their uncertainty of measurements, which led to a content-related motive for the concepts of accuracy (question 7 → 8). The motive to know 'how much stuff is allowed in the water?' (question 5) only became relevant for students after they had carried out the measurements with their water samples (question 7).

At the level of the framework, we identified a rather disturbing issue. The activity to produce drinking water from surface water disrupted the flow of activities (question 4). The students and the teacher were very much involved with the distillation and filtration processes [classroom observations & video-transcripts]. However, this activity shifted the emphasis from 'how to determine whether a water sample is clean enough for drinking?' to 'how can we produce water that is clean enough to drink?'. This shift in context involved a focus on different concepts, such as different production techniques and the influence of different water samples on the product. Consequently, this actually distracted the students from their original focus: to judge the quality of drinking water. As a result the activities of the second unit diverged in too many directions, and at this point the students (and their teacher) were not directed to the intended content-related motives.

The sequence of teaching-learning activities led to some of the intended knowledge needs and questions. The implementation of the 'need-to-know' principle was improved and the teaching sequence was more adequate with respect to the intended learning processes of the students. At the level of the framework the activities were not consequently planned within one context. This led to confusion when implementing the 'need-to-know' principle.

Results: Third cycle

(i) Incongruence: refined problem analysis

The use of a leading context-question only and the broad motive to answer that question did not serve as a sufficient heuristic guideline for implementing a coherent 'need-to-know' principle. The designer of a curriculum unit may select activities that generate the intended content-related motives in students for a chosen context. However, an inadvertent mixing of different contexts can easily occur. Therefore, according to this problem analysis, the relationship between the use and choice of context and the 'need-to-know' principle must be strengthened.

(ii) Selection, combination and generation of theoretical notions

We redefined 'context' as 'practice', since it not only defines the specific situation, but also the type of actions together with the necessary knowledge to be able to perform these actions. This redefinition of context is inspired by activity theory (Van Aalsvoort, 2004; Van Oers, 1998; Vygotsky, 1978). It has led to the principle of establishing an instructional version of an authentic practice (Bulte et al., 2005; Westbroek, 2005). Several 'authentic practices' can be found in society, and related to chemistry (or science in a broader perspective). To participate in a practice and to work towards a solution to practice-related problems, skills, attitudes and knowledge in and about science play an essential role. Van Aalsvoort (2004) proposed to try out different roles of social [chemical] practices by simulating these roles in the school setting. By experimenting with different roles of different practices, students are expected to perceive which roles appeal to them, and experience their activities as meaningful.

Related authentic practices can thus serve as a source of inspiration, and moreover as a heuristic guideline for the precise selection of activities within one curriculum unit: the instructional version of an authentic practice. This strategy allows the designer of the unit to create one clear, meaningful flow of activities. It therefore enables a designer to avoid the choice of activities that disturb the flow of activities (the production of drinking water) and 'scrutinizes' the intended 'need to proceed to a next step' (the judging of the quality of drinking water), a confusion occurring in the second cycle.

(iii) The design of the formal curriculum

The third version was thus designed as an instructional version of an authentic practice: judging the quality of water that has a certain function and should meet the corresponding criteria.. We included this strategy within the four-phase problem posing framework with adapted phase-descriptions (Table 3). Students were expected to become motivated by the purposes of the authentic practice to adopt their role in its instructional version. They would thus find out ('as interested students') how people in the authentic practice judge water quality by imitating that authentic practice. The students' intuitive knowledge of a procedure to judge water quality was used to design a problem posing teaching-learning process, thus creating an instructional version of the procedure of the authentic practice. This is reflected in the fact that the sequence of phases is similar to that in the second version. The exemplary problem here concerned the authentic case to monitor the quality of drinking water in a neighbourhood with two water supplies, drinking water and household water. Mistakenly, in the past the two networks had been misconnected and some citizens had accidentally drunk household water for some time.

Following the evaluation of the second cycle, the sequence of some sub questions differed compared to second version. For example the former question 7 has now become sub question 3.

---- INSERT TABLE 3 ABOUT HERE ----

(iv) The identification of the operationalised 'need-to-know'-design principle

The new framework with its sequence of activities derived from the sub questions guided the evaluation of the third version of the unit (Table 3). The operationalisation of the need-to-know principle was to have students adopt their role in the instructional version of the authentic practice to find out (as interested students) what this practice is about and what it takes to judge the quality of water. This role-adoption must ensure a coherent content-related motive within a problem posing sequence of activities (Table 3). This new set of expectations gives the following research question for the evaluation in the third cycle:

> Did the four-phase framework and its sequence of sub questions evoke that students were motivated by the purposes of the authentic practice to adopt their role, and did

they experience at the intended moments the intended content-related motives to extend their knowledge in the intended direction?

<u>(v) The evaluation</u> shows that the flow of the activities was generally more meaningful to students in the sense that their content-related motives ('need-to-know') emerged as expected (although not always) [video-transcripts & observations]. As a result students expressed in different ways [questionnaire & post-intervention interviews] their appreciation of the logic of the flow of activities. The students became involved in the practice of judging water quality (question 1) and in the case of the two water networks (question 2). The content-related motive to know 'what is in the water' (question 3) was not directly raised, although this could have taken place by extending the laboratory assignment using microscopes. After the students measured their water sample, a motive to compare their outcomes with legal norms was induced (question 4 → 5). This, in turn, raised uncertainties concerning the results of their measurements (question 4 → 5 & 6), although the outcomes clearly exceeded the norm. This was expected based on the evidence from cycles 1 & 2. Thus, without extensively addressing the question 5 & 6, question 7 could be answered: the quality of the water sample did not meet the criteria. Some students mentioned [questionnaire & post-intervention interviews] that it was sometimes unclear what you had to do (activities related to question 5). When the outcomes of the measurements would have been closer to the norm, the questions 5 & 6 would have been more relevant for the students. Then they would have had to consider much more explicitly the concepts of accuracy, reliability and validity (as had taken place in the final discussion in cycle 1, and as also had taken place in a follow-up field test).

Half of the students mentioned that they did not see the point of the last activity (making a report and a manual, question 8) [questionnaire & post-intervention interview]. This finding also followed from our analysis of the classroom observations and the video-transcripts.

Our final test results (attained curriculum) shows that more than 70% of the students (n=22) adequately understood why and how to use standard parameters to evaluate quality, and how to interpret norms. About 60% of the students related specific parameters to certain water functions, and showed an adequate notion how experiments could be considered as reliable. About 80% of the students adequately identified the issue knowledge involved in testing water quality.

The first three phases of the framework were thus adequately designed: the intended flow of activities on a 'need-to-know' basis is coherently designed, although some activities need some fine-tuning, and most students acquired the intended knowledge. The last phase (reflection) did not fit within the flow of activities, because students did not experience a need for expressing 'what it takes to judge water quality' in a more general sense.

Results: The (in)congruence after three cycles

When wrapping up this case study, we need to reflect to what extent our developmental research has addressed the initial curriculum problem adequately. For this we selected relevant transcripts of questionnaires and post-intervention interviews of the students after the third cycle.

Most students reported that they appreciated the unit more than their regular chemistry education. Students wrote that they especially appreciated the feeling that you could discover things themselves:

> 'You are much more independent in this project. Normally the teacher shows you exactly what to do and here we could find out things ourselves.'

Also, some students reported that they better understood why they had to perform lab activities. They referred to a sense of purpose [questionnaire & post-intervention interview]:

> ‘We were doing real experiments, with a purpose.’

As the following quotations show, the students expressed in their words the views that our designed unit (third version) did contribute to the reduction of the incongruence between ideal, experiential and attained curriculum representations. They expressed [post-intervention interview] this when comparing their regular textbook with the unit about ‘Water Quality’:

> ‘You know all the time why you do things, like the experiments…’
>
> [Other student adds:] ‘Yes, like the lab-work we are doing now [referring to some recent experiments in the regular chemistry lesson], I don’t know what we are doing. Ok, I do it, but for what? What does it mean?’
>
> ‘I enjoyed it better than the book, because now we knew what we were doing with those experiments. Why you are doing these, what you are actually doing, and why.’

In their own words, students indicated that our unit was meaningful to them, that they were doing activities with a sense of purpose, and that this ‘why and how’ was missing in their regular chemistry lessons.

The strategy to solve the curriculum problem at the level of one unit can now be more precisely described. All activities, including the reflection, must be embedded in the instructional version of a practice; the message about ‘what is to be learned’ must fit within this practice. At the level of some of the detailed activities the main challenge is to embed the activities coherently within the practice from the perspective of students.

The strategy to establish an instructional version of an authentic practice appeared to be relevant for the sequencing of the phases and the activities, for the roles of the students and the teacher. It also provided guidelines for the decisions about the procedural and conceptual knowledge needed in the activities. The third framework did generate a sequence of sub questions that to a large extent evoked the intended students' knowledge need. However, the last phase (reflection) did not fit within the coherent flow of activities.

As a framework for student learning we therefore propose to compose an 'instructional version of authentic practice' as a design principle. Its main challenge is to limit one unit to one practice, and to avoid sudden change of 'roles': at the start students should identify with a role, and at the end of a unit they should reflect, not only about the exemplary problem but 'what it takes to solve such society-relevant problems'. The use of authentic practices does not serve to educate students as experts (mini lab-analysts or mini scientists). But for students these practices are a means to learn some concepts that are valued by our society, and to learn how this knowledge functions in society. It fits with a problem posing phase description, slightly adapted on the basis of our findings, including an extra phase at the end that places special emphasis on reflection (Lijnse & Klaassen, 2004).

To answer our research question, in summary, we now present a revised general framework for the instructional version of an authentic practice as a new hypothesis for the design of a curriculum unit with a coherent 'need-to-know' principle (Table 4), as it has been developed with a domain specific in-depth case-study with an exemplar unit about 'Water Quality'.

---- INSERT TABLE 4 ABOUT HERE ----

Discussion and Implications for other units

Our conclusions and this discussion have been based on the extensively investigated case-study about the unit ‘Water Quality’. This was an in-depth case study consequently with a limited number of participants: five teachers at three different schools in total with their students in some of the classes for initial chemistry education. Conclusions evidently are limited to these situations at this stage of the national curriculum development. We have reason to believe, however, that our findings are supported by evidence from some of our other case studies, and those investigated by others.

Some other units were developed on the basis of the three-phase framework that we used in our first studies (see first cycle and other papers (Bulte et al., 2005; De Vos et al., 2002)): a unit about super-absorbents, and a unit about washing processes. For example, with respect to the unit about super-absorbents, we found that students did not see the relevance of learning about organic chemistry presented in the textbook chapter after the introduction of the context about disposable diapers. While studying the textbook chapter, the students lost their initial questions that were raised when they were confronted with the water-uptake of the super-absorbent material in the diaper. Besides, at the end of the unit, when students were asked at the final presentation of their projects to show how they applied the concepts of organic chemistry, they did not link these concepts to their own projects. These findings support our conclusions with respect to an inadequately designed ‘need-to-know’ in the first cycle. The units were developed considering a ‘need-to-know’ from the perspective of the expert, the chemist, not from the perspective of the students. These findings are also in line with a closer analysis of earlier PLON materials about the contexts ‘The weather’ and ‘Traffic’ for physics education.

We have used the framework of authentic practices to understand the strength of a unit in which students meaningfully learned the concepts of evidence (Gott & Duggan, 1998) that are typical for research practices (Van Rens, 2005). The unit starts with an introduction to the process of inquiry: accurately and reliably performing an investigation. In the introduction students are provided with an orientation on the issue of diffusion of particles as a function of the mass of these particles. The students get a demonstration of an experiment and study an adapted publication of an authentic investigation (Nemetz & Ball, 1995), in which the authors propose a relation between the diffusion of ions and their masses. The students repeat the presented experiments and by doing so they express their prior knowledge about the issue (ions, precipitation and diffusion) and about aspects of concepts of evidence. From this they conclude that they need to reproduce the experiments themselves to be conclusive. The students plan their own investigation. They obtain their own data and draw conclusions. They report about their findings and submit their article to an internet 'research community' in which the findings of the 'researchers' from five different schools are compared. The students are included in the process of peer review: they give feedback on the articles, the conclusions, the results and the underlying methods. Subsequently, the students are invited to improve their articles. This unit can be identified as a typical adaptation of an authentic research practice (Bulte, Westbroek, Van Rens, & Pilot, 2004). Both the students, as junior researchers, and the teacher, as their supervisor (respectively), maintained their 'authentic' roles, which was in retrospect one of the most effective features for successful implementation (Van Rens, 2005).

Our framework is now being used for new case studies to arrive at a coherent need for some (chemical/science) knowledge concerning other crucial aspects of the curriculum, and to select appropriate content (concepts) for the chemistry curriculum.

As a possible strategy to address learning problems described for models and modelling (Erduran & Duschl, 2004; Grosslight, Unger, Jay, & Smith, 1991) we proposed to meaningfully embed a modelling activity within an instructional version of an authentic practice. Therefore, we have identified and analysed some authentic practices using criteria we have taken from a survey among students in the UK (Osborne & Collins, 2001). The practices' typical problems, the motives for addressing such problems, the characteristic modelling procedure and the (chemical) knowledge used within these practices were used for adaptation into instructional versions for educational purposes (Prins, Bulte, Van Driel, & Pilot, 2004). We found that for two practices the starting activities of the instructional versions led to students generating a content-related motive to adapt and reconstruct a model (Prins, Bulte, Van Driel, & Pilot, 2005).

Furthermore, typical problems of appropriate authentic practices have been used to analyse structure-property relations (Meijer, Bulte, & Pilot, 2005). This has been carried out to address leaning problems concerning micro-macro thinking and the particulate nature of matter (Harrison & Treagust, 2002). Typical production practices were identified for developing improved materials and adjusting food properties. These practices were used to make explicit a conceptual analysis of structure property relations in several intermediate levels from macro-, to meso- to micros-structures (Meijer et al., 2005). The authentic practices, in which micro-macro thinking is meaningfully used, will form the basis for the design of instructional versions to improve micro-macro thinking with students.

Conclusions: the evidence-based development of one curriculum unit

Related to Figure 1b, we defined the following intended outcomes of developmental research:

(i) an appropriate understanding of the curriculum problem,

(ii) the selection, combination and generation of appropriate theoretical notions,

(iii) an empirically based curriculum unit and its underlying framework,

(iv) insight and understanding of evaluation processes in curriculum development and,

(v) its evaluative outcomes.

In this section we briefly describe these outcomes as they follow from one in-depth case study and from comparison with other findings.

In terms of involving students in appropriate practices in which certain concepts play a meaningful part, the current curriculum problems (outcome i) can be understood as meaningless learning of abstract concepts detached from the original (research) practices in which such concepts were developed. This actually rephrases De Vos' problem analysis:

> '… modern chemistry books present students with a set of selected truths detached from their scientific origin.' (De Vos et al., 2002; p 108)

In addition, we state that the usual concepts of the present-day curriculum belonged to scientific practices of the late 19th and early 20th century with typical activities to analyse and classify substances, and understand fundamental properties and structures of materials. It is not only that chemical knowledge has grown; the nature of present-day activities has changed both in technological practices and in research practices, with more emphasis on product development, creating new synthetic pathways & processes and its necessary underlying understanding. (Re)connecting the learning of traditional concepts (again) to contemporary contexts does not automatically resolve this problematic situation. Superficially, contexts and concepts may somehow be related, but on the level of activities a mismatch may occur between a practice-related problem, the type of planned activities and the concepts involved (see e.g. our second research cycle).

A second part of the new problem analysis involves the planning of the activities and concepts within one practice. The sequence of activities may be evident from the perspective of the experts, the chemist. This does not automatically mean that students experience this 'evident' connection, as we have identified in our first cycle. The student is unfamiliar with both the necessary detail of the practice (as context), and with the concepts that operate within it.

These two interrelated problem descriptions may explain why sometimes the intended concepts are not connected to the context (Parchmann et al., this issue), or in cases when students are asked to express their argued opinion on socio-scientific issues (Sadler, 2004). We may hypothesise that from the students' perspective a meaningful connection was not established between the authentic problems and the concepts intended to use and to learn. The planned learning of concepts may not fit meaningfully in the problem-related practice, the planned teaching and learning sequence may not be designed from the perspective of the students, or a combination of both.

We have made use of some appropriate theoretical notions (<u>outcome ii</u>) to address this refined problem analysis. Firstly, we applied activity theory to select practices with their related concepts thus avoiding abstract and unrelated concepts (Van Aalsvoort, 2004). Secondly, a problem-posing approach guided the planning of activities in such a way that students see the rationale for extending their knowledge in the desired direction at every step (Lijnse & Klaassen, 2004). In our framework, we have combined these theoretical notions to adapt an <u>authentic practice</u> into a version that is designed from the learning perspective of the student (its <u>instructional version</u>).

An empirically based unit has been developed with its underlying general framework (Table 4; outcome iii: see description in the previous section).

The research method we have illustrated here with the development of an exemplar unit (outcome iv) mirrors the operational, experiential and attained curriculum (at the level of one unit) with the ideal curriculum in several cycles. It is not (at this point) our aim to compare the learning outcomes and the students' preference of one (traditional) curriculum over a new one. Such a comparison can only be done after developing a unit with empirically determined instructional quality. Only then a valid comparison could be useful, and only if comparison can be made on 'fair' grounds. When the learning aims of the different curricula are very different, the learning outcomes cannot be compared. But, our research method can give an empirically-based evaluation whether new curriculum units live up to their intention. In curriculum development not all units to be developed can be subjected to such in-depth research. A selection of key units at some critical points in the curriculum may serve as a way of communicating design principles.

Implications for curriculum development: connecting the units

So far, we discussed our contribution to addressing the curriculum problems at the level of one unit. This leaves open the problems at the curriculum level. Firstly, we have argued that it seems reasonable that different authentic practices are suitable to adapt for educational purposes. The question now is: how can separate units be connected in such a way that for the entire curriculum students have a proper sense of direction of what comes next, and understand why they have to learn something at every step of the curriculum. We have developed tentatively a framework to provide students with motives to proceed to the next stage within a unit. But how to provide students with motives to proceed to the next unit or to the next set of units? The question we therefore need to ask is: how can we compose a clear flow of units through the curriculum, a leading thread, similar to the case a single unit. How to provide for motives, based on intuitive notions about what is the next 'logical' stage in the story. Secondly, in relation to the first issues, how to enable students to use the chemical knowledge as they have acquired it in one practice to become meaningful in another practice?

Based on our ideas, we describe a first attempt to address these issues as a hypothesis. The examples described in this section are only meant to illustrate how one practice can be meaningfully connected to the next, and how different types of practices can be sequenced as a 'balanced' selection of different curriculum emphases (Roberts, 1982, 1988). Instead of describing curriculum ideas in very general terms, we choose to illustrate our ideas with specific examples, and speculate that this story could start as follows. In our society we deal with all kinds of consumer products. So what does it take to evaluate whether a product is good enough, for example, the quality of water, the quality of marmalade, and the quality of products for personal hygiene? While studying this type of practices, we have shown that students realise the relevance of concepts such as 'what are the components of the product, what stuff is in it, how much stuff is allowed, how accurate and reliable can this be determined?' These practices (emphasis on Quality evaluation) can be connected through a procedure of quality evaluation. In the connection from one practice to the next, concepts about composition may be extended connecting prior knowledge about the composition of water acquired in one unit to the composition of more 'complex' products in a next unit. Gradually students may start to wonder: we evaluate this product, but 'How is this product being made? What, if a product is not good enough, but we want it to meet some criteria. Why is it difficult to prepare such a product?' This can provide the students with a motive to proceed to the next set of units about a new type of practice (emphasis on Production), e.g. the production (and its modelling) of drinking water that is below the nitrate norm, while ground water contains a far too high amount; or the preparation of ready-to-eat fresh food, while the consumer does not want it to be radiated. In such practices students can learn how to prepare a product or how a certain component is synthesised thus meaningfully introducing the concept of structure – property relations. The introduction of this concept can be built on the students' knowledge of the composition of products, acquired in the practices about quality evaluation. A meaningful extension of structure – property relations gradually can take place when dealing with the production and subsequently the synthesis of products that differ in complexity. But what if we cannot synthesise what we wished to synthesise, if we lack some fundamental understanding of a route for synthesis, or if we need to investigate alternative routes, nobody has followed before? For example, the development of smaller and smaller electronic devices, how to synthesise self-arranging nano-structures that show the desirable conductive properties? Such questions can provide students with motives for getting involved in research practices (emphasis on Research), which deal with such fundamental questions, and meaningfully involve the more abstract chemical concepts connected to prior knowledge acquired in the preceding types of practices.

All these practices can come together in a fourth type of practices, in which professionals have advisory functions, communication functions or educational functions (emphasis on Multidisciplinary practices*)*. In these authentic practices, professionals need to integrate knowledge from different disciplines, diverse procedures and attitudes. Perhaps a project could involve solving a crime, the detectives, the forensic department, asking for advice from a team of experts, communication with the public, etc. In such a project, other school subjects can be involved: languages, social studies, biology, etc. Such projects can be a final project of the curriculum line, but could also be planned at intermediate stages, or even at the very start of a curriculum as a first orientation what chemistry (science) may involve.

At this point we need to stress that such a sketch of a curriculum line is highly hypothetical in nature. It is inspired by the empirically based development of a framework for one unit, but leaves open the questions how to select a set of core concepts at the level of the curriculum that does not lead to overload, that can be meaningfully acquired by students, and that allows the flexible use of concepts from one practice to the other. The framework of chemistry (science) education based on authentic practices is proposed as an alternative route to select new content for the chemistry curriculum: selecting practices together with the different stakeholders to illustrate activities that fit with what a society values for secondary chemistry (science) education (Lijnse & Boersma, 2004). And from this starting point, to select matching contents. Or at least a two-way route: pre-select some leading ideas that should be in the curriculum and pre-select some practices, and make the jigsaw puzzle fit. Not only does our new framework contribute to the development of a coherent 'need-to-know' for some (chemical) knowledge, it also can serve to escape from the traditional curriculum contents which we all have been so attached to and find difficult to escape from (Van Berkel, 2005). It is this fundamental contribution we expect to be of importance for our national curriculum development, and we hope that it stimulates the discussion about chemistry (science) education in the international community.

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Captions to the Tables and Figures

Three figures were also separately send as GIF files.

Table 1 Phases and corresponding sub questions that frame the activities of the first version of the unit.

Table 2 Phases and corresponding sub questions that frame the activities of the second version of the unit (the numbers between brackets refer to the related sub question in the first unit).

Table 3 Phases and corresponding sub questions that frame the activities of the third version of the unit (the numbers between brackets refer to the related sub question in the second unit).

Table 4 The emergent revised hypothetical framework.

Figure 1 Representation of the cyclic (spiral) character of developmental research, a: depicted from a 'top-perspective', b: depicted from a 'side-perspective'.

Figure 2 The 'ingredients' of the exemplar curriculum unit about 'Water Quality'.

Table 1

First framework: phases & phase-descriptions	***Sub questions that guide the activities***
I. Orientation & motivation	1. What are we going to do these five lessons?
	2. Judging water quality: what steps are involved?
	3. What information do you need to be able to judge the water quality?
	3A. What things should you take into account if you want to judge the water quality?
	3B. What is a suitable sample site?
	3C. What are relevant parameters and norms for the measurements of your water sample?
	4. What do we 'need-to-know' to formulate a *reliable* judgement of the water quality?
II. Extending knowledge	5. How and how accurate can we determine the parameters?
III. Applying knowledge	6. Can we apply our knowledge to an example?
	7. Is 'our' water clean enough for its function?
& Reflecting	8. Did we adequately judge the water quality of the water in our neighbourhood? 9. What is the common procedure for testing and judging water quality?

Table 2

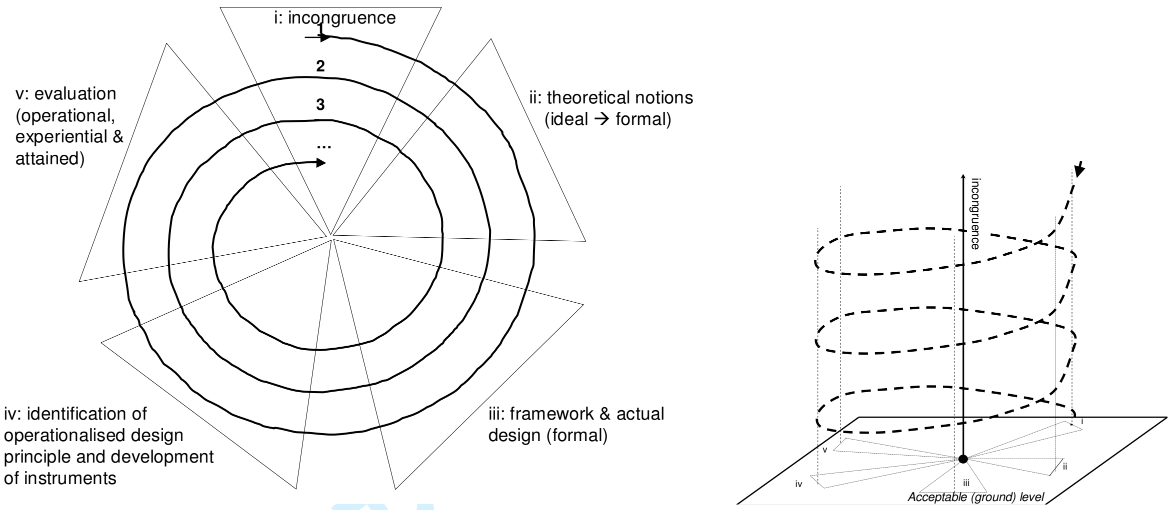
Second framework: Phases & phase-descriptions		***Sub questions that guide the activities***
1	General orientation on a leading context-question concerning several cases in which quality judgement is involved raises a motive to find out about 'what is involved'.	1. What is the lesson series about? (1)
		2. What is the leading context-question for judging water quality and, roughly, how are we going to answer this question? (1)
		3. Which relevant experiences do we already have with judging water quality? (new, includes the students' intuitive notions of 2, 6 & 7)
2	Using the existing, intuitive notions of 'what is involved' in a specific exemplary situation induces a 'knowledge need' (content related motive) in a certain direction.	4. Did we produce drinking water quality? (new)
3	Extending knowledge in the direction of the induced knowledge need.	5. What stuff and how much of it is allowed in drinking water? (6)
		6. What parameters should we measure and how can we do that? (what is an appropriate procedure?) (3C)
		7. What are the results of the measurements? (is the water clean enough to drink?) (7)
		8. Do we trust the results? (is the water clean enough to drink?) (3 & 4)
4	Reflection on the procedure of the context.	9. In what sense can we apply the followed procedure in another situation of water quality judgement (like: is the water quality of a ditch clean enough for its ecological function)? (9)

Table 3

	Third framework: phases & phase-descriptions	***Sub questions that guide the activities***
1	Students are to feel motivated to get involved in the instructional version of the practice. They are to get a clear view of its purpose (to solve practice-related problems), the way (procedure) they are going to achieve this, and their role in it.	1. What is involved in water quality judgement? (1 & 2)
2	Students experience that they have intuitive notions about the procedure to solve an exemplary problem, but that their intuitive notions about specific issue knowledge are not sufficient, thus inducing a 'knowledge need'.	2. Does the water sample in the exemplary problem of the two water networks meet the quality criteria for drinking water? (3)
3	Students are to extend their issue and procedural knowledge in progressive cycles in the direction of the raised 'knowledge need', until a satisfactory procedure is reached.	3. What does the water sample contain? (7)
		4. Does the water meet the quality criteria for drinking water? (5)
		5. Do we trust the list of tested parameters and their norms? (6)
		6. Do we trust our test results? (8)
		7. Does the water meet the quality criteria for drinking water? (new)
4	Students are to reflect on 'what they have learned to solve the exemplary problem': a characteristic procedure for the practice.	8. To what extent can the procedure we used (judging water quality) be applied in the other exemplary problems of phase 1? (9)

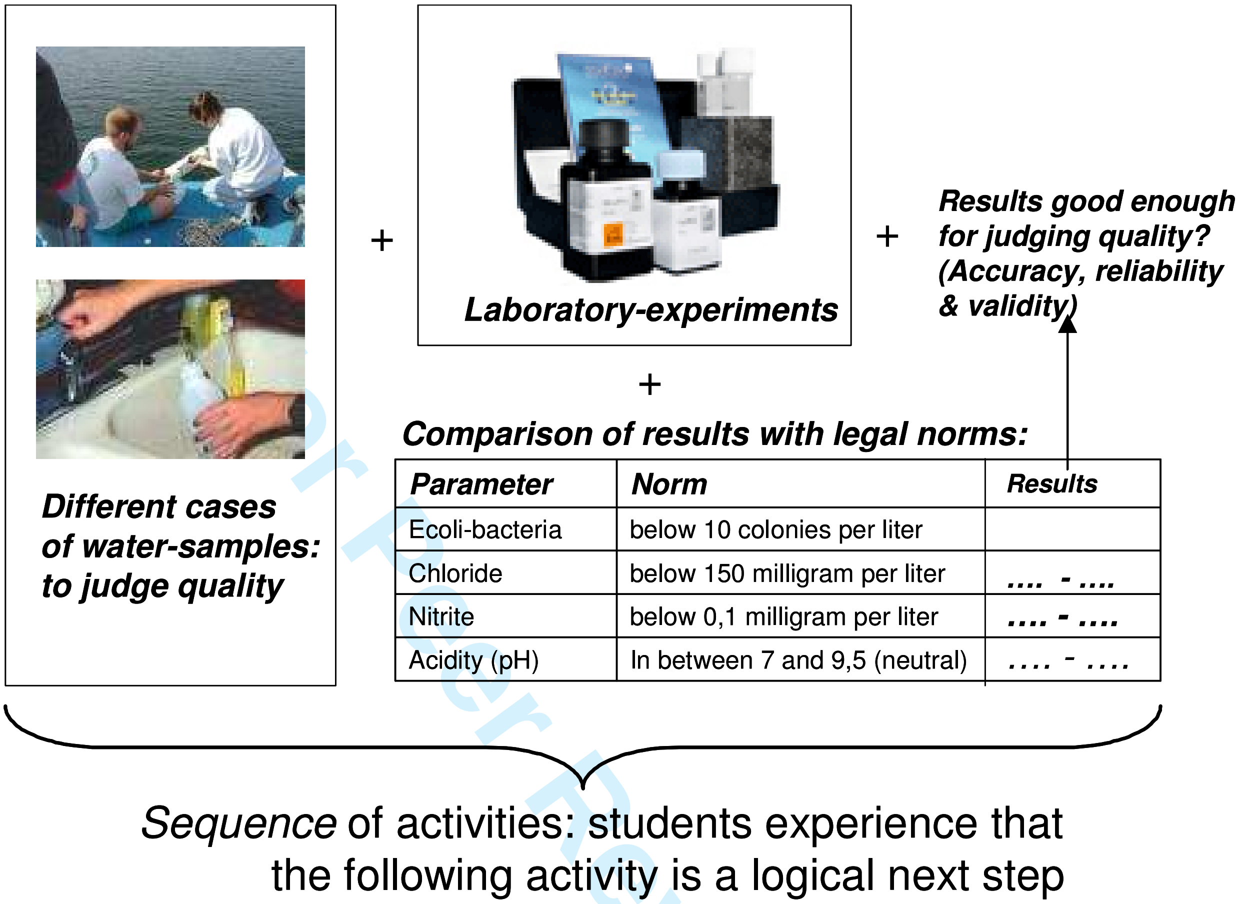
Table 4

The revised framework: phases & phase-descriptions	
1	During the general orientation on the practice, students start to recognise typical problems that are posed in such a practice, and at the same time they discover that a general characteristic procedure of the practice typically leads to solutions to these problems. Because of their appreciation of the purpose served by solving such problems, students become motivated for an imitation of the authentic practice, focusing on an exemplary problem.
2	By a first analysis of the exemplary problem, their intuitive notions concerning the issue and their common sense (intuitive) notions concerning a characteristic procedure are expressed and used. Students realise that for solving this exemplary problem, their issue knowledge is not sufficient. That is, they realise that they *need to learn* more detailed issue knowledge.
3	Students proceed through the steps of the procedure working toward a solution of the exemplary problem, whilst extending the relevant knowledge, and when necessary, also refining steps of the procedure, until a satisfactory procedure is reached, and a solution for the problem can be presented.
4	Students realise that they need to express the necessary steps of the procedure when solving (one or more of) the other problems that are typical for this practice.
5	Students make a project plan for solving another problem typical for the practice. By doing this they explicitly use the complete operational procedure, they have developed in phase 3.


i: incongruence
1
2
3
...
ii: theoretical notions
(ideal → formal)
iii: framework & actual
design (formal)
iv: identification of
operationalised design
principle and development
of instruments
v: evaluation
(operational,
experiential &
attained)
incongruence
Acceptable (ground) level
i
ii
iii
iv
v

a. *b.*

Figure 1



Parameter	Norm	Results
Ecoli-bacteria	below 10 colonies per liter	
Chloride	below 150 milligram per liter	.... - ....
Nitrite	below 0,1 milligram per liter	.... - ....
Acidity (pH)	In between 7 and 9,5 (neutral)	.... - ....

Figure 2

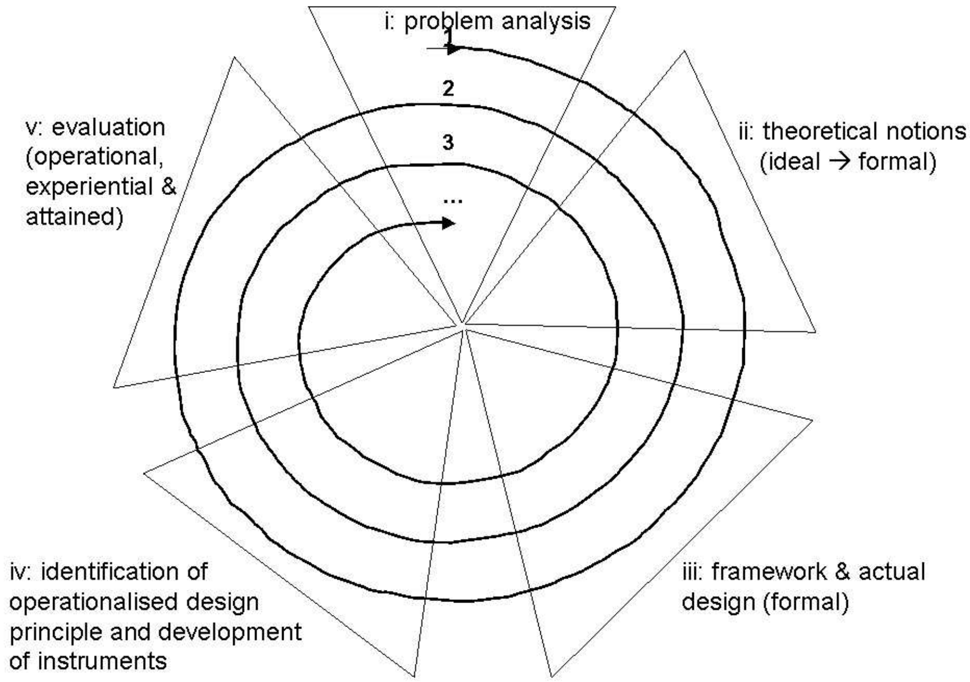


Figure 1 Representation of the cyclic (spiral) character of developmental research, a: depicted from a 'top-perspective', b: depicted from a 'side-perspective'.
338x254mm (72 x 72 DPI)

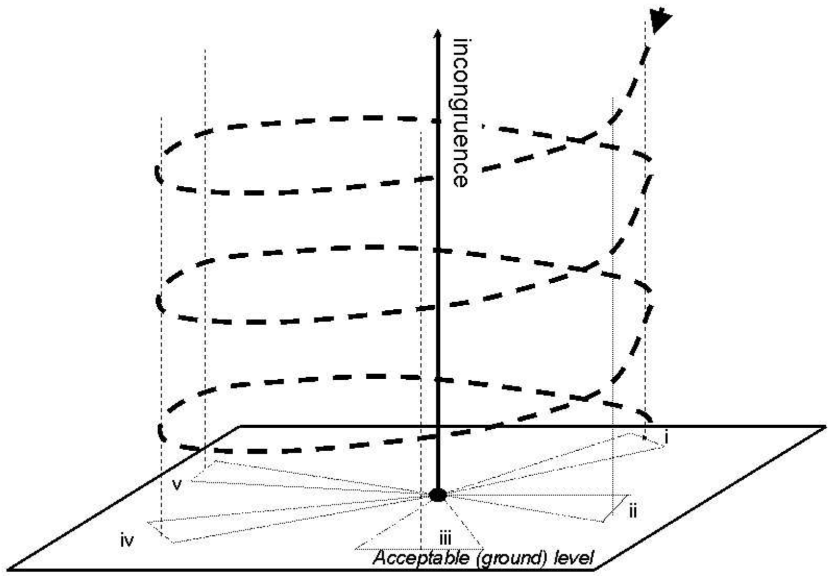


Figure 1 Representation of the cyclic (spiral) character of developmental research, a: depicted from a 'top-perspective', b: depicted from a 'side-perspective'.
338x254mm (72 x 72 DPI)

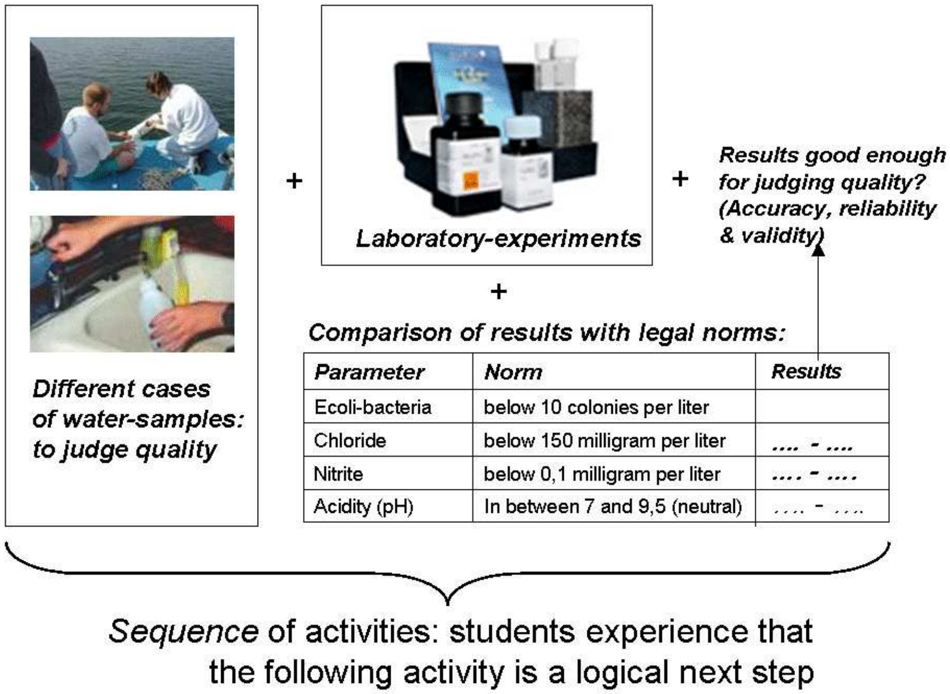


Figure 2 The 'ingredients' of the exemplar curriculum unit about 'Water Quality'.
338x254mm (72 x 72 DPI)