Characteristics of meaningful chemistry education

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Abstract

Secondary chemistry education contains problematic features, as a result of which the subject does not appeal much to students. We will elaborate upon these problems and also upon potential strategies to solve them. Our aim is to make insightful that the question 'how to design 'meaningful chemistry education' is in fact underestimated in the field of science education research. To answer such a question the quality of the design, that is, the extent to which it gives rise to meaningful chemistry education, should be object of research. This is rarely done. We will show that when this is made object of research, other questions are raised than the questions generally addressed in similar projects, and as a consequence a different research strategy is needed.

1 Introduction

In this paper we aim to contribute to the ongoing discussion about how chemistry (and broader: science) education could be revised in order to make it more *meaningful to students*, in the sense that they are able to identify with the issues raised and have a sense of direction of 'where it all leads to'. That there are indeed problems in secondary chemistry education, follows from several analyses of chemistry (science) education, which we will briefly discuss in section 2. They reveal three main problematic features of chemistry education, which play a role on curriculum level, on the level of one module, and on the level of one lesson. These features, 'rhetoric of conclusions', 'inconsistencies' and 'lack of student input', are argued to contribute to an experienced alienation and lack of sense of direction by students. Next, in section 3, we will describe how several projects, both small scale and on a curriculum level, in their attempts to overcome these problematic features all embody three intertwined characteristics of what we have called 'meaningful chemistry education': a 'context', a 'need-to-know' and a 'students feel that their input matters' characteristic. This framework of solution strategies seems to provide for useful design directions for meaningful chemistry (science) education. Nevertheless, none of the projects seems to make the teaching learning process and the quality with which these characteristics are given content in the design object of study. It seems to be a neglected and underestimated field of research. In section 4, we will argue that if the design is object of study, the question being if, how and to what extent it gave rise to meaningful chemistry education, a specific research strategy called developmental research is needed. Accordingly, we have designed and developed one module and have studied the realised teaching learning process in detail. Finally, in section 5, we will discuss how we think this strategy, although it involves one module, leads to more general hypotheses about what could be features of meaningful chemistry education.

2 Problematic features of chemistry education

Three problematic features of chemistry education can be distinguished, which contribute to an experienced alienation and lack of sense of direction by students. A first one we call, following Schwab (1962), the 'rhetoric of conclusions'. De Vos et al (1990, 2001) describe the first feature as the reduction over time of chemistry education to a presentation of selected results of chemical research. A success story, which leaves the process of how people came to these results (or worse: the fact that *people* came to these results), and why they bothered, unanswered. It is hardly surprising that this leads to alienation and a lack of sense of direction of students. In school chemistry, were ideas and models and theories are introduced 'as such' and without a clear purpose, it is impossible for students to have even a remote idea of 'what comes next'. That automatically leaves the chemistry teacher completely in charge of the content related progression. He or she is the only one with an overview.

The second feature concerns inconsistencies of content. Two related types of inconsistencies can be distinguished: on the level of concepts and on the level of curriculum emphases. De Vos et al. (2001) describe an inconsistent 'layer-like structure' of school chemistry, which leads to inconsistent meanings of concepts. Roberts describes inconsistencies on the level of 'implicit shifts between different curriculum emphases', which lead to inconsistent messages about the purpose of learning certain content (Roberts, 1982, 1988, 1995). The following typical example shows how implicit shifts between different emphases in (in this case) a textbook produce confusing messages to the students about 'why are we learning this?'. Try to put yourself in the position of a student as we go through the first section of the chapter where 'acidity' is introduced in a widely used Dutch chemistry method for lower level secondary education. It starts with a story about the way different foods taste differently (sour, bitter, salty). Next, students are to *test* different 'daily life' liquids like ammonia, vinegar, lemon juice. They use something like an 'indicator', and are supposed to categorise the tested fluids into the categories 'acid', 'neutral' and 'basic' based on their test results. Immediately after these experiments the concept of acidity (pH) is introduced, as a refinement of the categories. The whole reason for this categorisation and what it has to do with different tastes is not made explicit for students, because there is no reason. This is the point were you, a student, might ask 'why am I doing this?'.

Besides the features of the school chemistry content, there is another, but related, feature of chemistry education, which contributes to the lack of sense of direction of students and their alienation from school chemistry. The limited input of students in the learning process is also an, again widely, recognised problem in physics and science education. Lemke (1990), for example, observed classroom dialogue in traditional science lessons. He describes how these are dominated by whole class interaction and the three-turn sequences dialogue structure he called 'triadic dialogue structure'[1], preventing students to ask questions, which could indicate self-directed learning (Lemke, 1990; Rop, 2003; Watts et al, 1997).

3 Potential solutions: characteristics of the concept of meaningful

There have been several attempts to pay attention to the problematic features of chemistry (and science) education described in section 2, by designing more 'meaningful' methods. They range from more or less isolated projects, designed as small-scale experiments or welcome additions to the existing curriculum, to projects, which aim to reform the curriculum. Although not explicitly labelled as such, in both the small-scale and large-scale projects three intertwined 'characteristics of meaningful' generally can be seen to play a role. First, in section 3.1, we will give a brief tentative description of these three characteristics and how they can be interpreted as solution strategies for the detected problematic features. Next, in section 3.2, we will discuss some projects and indicate in what sense they embody, in our view, these three characteristics of meaningful. We will also indicate what kind of evaluation studies were carried out with regard to these projects and what the main findings were. In section 3.3, we conclude that, although the discussed projects all more or less aim to address the same problems and all embody the three characteristics, a thorough underpinning and evaluation of the designed teaching learning process in terms of the three characteristics is generally lacking. This points at a neglected research area, which we will further explore in section 4.

3.1 The first outline of three characteristics of meaningful

Before going in to the different projects, we will briefly describe what we consider as three characteristics of meaningful. This description is based on a general analysis of a variety of projects. At this point we only very tentatively indicate how the characteristics can be considered a solution strategy for the problems described.

First characteristic: context

A well-defined, for students recognisable context for concepts, motivates them and provides the related concepts with a distinct function and therefore meaning. The 'rhetoric of conclusions' feature can be avoided, when the emphasis is shifted from 'getting an overview of the conceptual products of chemistry' to the 'functionality of concepts in relation to a certain relevant, recognisable context'. A *consistent development of concepts* can be achieved this way (as they are to have a 'distinct function and meaning').

Second characteristic: need-to-know

Addressing students' questions on a need-to-know basis, which also implies building properly on pre-knowledge of students, provides for an increasing involvement of students in the teaching-learning process as they will see the point of what they learn every step of the way. This characteristic, together with the first characteristic of a well-defined context, can provide for the development of a *consistent emphasis.* The question 'why are we learning this?' can be captured in the need–to-know approach.

[1] teacher question- student answer-teacher evaluation

The first and second characteristic both contribute to the diminishing of the inconsistencies (see section 2).

Third characteristic: attention for student input

The third characteristic is closely related to the second characteristic: if one pretends to really incorporate a need-to-know approach in the design of a teaching-learning process, then ‘real attention for student input’ is inevitable. Students will get more insight in and will experience the functionality of ‘what comes next’, as a result of such a need-to-know approach. As another result the teacher will have more opportunity to pay real attention to their input, which now could become a driving force of the content related progression. Consequently, students will *feel that their input matters*. Obviously this characteristic addresses the problem of ‘lack of student input’.

3.2 The three characteristics of meaningful in different projects

The following projects can be seen as striking examples of the wide range of projects which in our opinion all embody the three characteristics of meaningful: PLON, Salters’, ChemCom, Chemie im Kontext, The Wide River Project and Chemistry in Products. All these projects aim to address problems similar to what we described in section 2 (although some projects lay different accents). We selected these particular projects because they are, in general, well-known projects and referred to a lot. They are generally seen as examples of successfully creating more meaningful chemistry or science education, at different times, in different places. This shows that the problems and solutions are generally accepted, but not new.

Within the scope of this paper we will only discuss two projects: Salters’ and the Wide River project. We do think, however, that this will give an impression of how we analysed the other projects. For both projects we will briefly go into its rationale, how the three characteristics can be seen to form the main outlines of the design and how they are accounted for. Finally, we will briefly go into how the projects were evaluated, especially concerning the three characteristics of meaningful. In the text it is indicated between brackets which of the three characteristics is addressed.

The Salters’ approach

A British initiative in 1983 to discuss how chemistry could be made more ‘attractive to students’ resulted, twenty years later, in a ‘whole family of science, physics and chemistry courses’ (Campbell et al., 1994).

Rationale

The idea was that a new kind of school science, more appealing to ordinary students, was called for. It would needed to be ‘more relevant to students’ interests and everyday lives, and would involve them in a wide range of activities in which they could actively engage’. The aim was that ‘the ideas and concepts selected, and the contexts within which they are studied, should enhance young people’s appreciation of how chemistry contributes to their lives or helps them to acquire a better understanding of the natural environment’ (Campbell et al., 1994, p418-419).

The Salters' approach was designed from the concept of 'narrative cognition' (Bruner, 1996).

The three characteristics in the design

The Salter's approach uses the idea of story lines as contexts. The story lines are to motivate and involve students in the learning of chemistry and to provide students with a more authentic picture of it (Campbell et al., 1994) [first characteristic].
The need-to-know approach was addressed as follows: the unfolding of the story line would, in a natural way, provide for motives at certain points to get a deeper insight in scientific ideas and concepts. Or at least, the continuing story would provide for a context in which the concepts and ideas have a clear role and function (and therefore: meaning). In other words, students would experience a need for relevant scientific concepts and ideas to be able to 'follow' the story line, or would at least experience the functionality of the concepts and ideas in the light of the story line [second characteristic]:

'Units of the course should start with aspects of the students' lives, which they have experienced either personally or via the media, and should introduce ideas and concepts only as they are needed'

(Campbell et al., 1994, p419)

Moreover, the developers were well aware of the problematic fact that science teaching was 'heavily relying on the transmission of content knowledge'. To address this problem, they decided that the course should include a wide range of learning activities, which would actively involve students. They based their choice on the work of Barnes et al., Davies & Greene, Lemke, and Sutton, who emphasise the importance of the use of language by learners in the learning of science (see also the introduction: lack of students input). Many student activities were included to promote the use of student discussion in lessons. This can be interpreted in our opinion as contributing to third characteristic (Campbell, 1994, p419).

Evaluation

Evaluation studies of the project concerned a variety of fields ranging from 'comparing the understanding of certain chemical concepts of students using a context approach with students using a traditional approach' (Ramsden, 1997; Barker and Millar, 1996) to 'teacher's change as a result of teaching a context-based course' (Ramsden, 1994). It was not studied, though, in any detail how and to what extend the design of the teaching learning process had contributed to the three characteristics of meaningful: had students experienced a need to know with the unfolding of the stories? And did they as a result experience the chemical content as relevant and useful?

The Wide River project

The project is part of an initiative of the Centre for Learning Technologies in Urban School', and is a joint partnership with the University of Michigan, the Detroit Public

School System, Northwestern University and the Chicago Public School System. Its aim is to use innovative technologies in the design of project-based science curricula ‘to support learning’. The Wide River project (about water quality) is one of the modules produced by this group. Based on these modules the group wants to draw conclusions on the level of curriculum innovation.

Rationale

The authors refer to ideas like: active construction, situated cognition, community and discourse. The idea is that through inquiry students engage in investigations from which they learn scientific processes and how these processes work to generate new information. It is thought that this approach stimulates the ‘active involvement’ of students in the process of knowledge development and provides room and opportunity for students’ own interests and questions (Kraijeck et al.). This could be interpreted as an emphasis shift from ‘rhetoric of conclusions’ to ‘science as a human activity’. The ‘innovative technology’ merely concerns the fact that the project is presented on a website, which serves both as a source of information and as a means of communication (with teachers, other students, experts) This way the website is expected to form a platform for a ‘learning community’ (Rivet et al., 2000, p.6).

The three characteristics in the design

The Wide River project uses, what was expected to be a ‘relevant authentic’ driving question for students as a context: ‘what is the water like in our river?” [first characteristic]. The driving question is expected to ‘contextualise scientific ideas using students’ experiences’ and, as a result, to motivate students. Sub-questions introduce scientific knowledge the students are expected to ‘need-to-know’ in order to get a greater understanding of the scope and the depth of the driving question. The set of successive sub questions, are carefully derived from the driving question by putting oneself in the place of the students (Krajcik et al.; Rivet et al.2000). The driving question and related sub questions form the framework for learning [second characteristic]. At certain points benchmark lessons are used to ‘foster the understanding and connections between key scientific concepts. Teachers introduce domain specific terminology and processes during these benchmark lessons’ (Rivet et al., 2000).

The project is designed to foster students’ collaboration within a ‘learning community’ as students are seen as novices who have to learn to participate in a scientific community. This, of course, requires the use of scientific language. Students communicate with each other, teachers, community members and scientists to find information and solutions to *their* questions and to discuss *their* findings and understandings [third characteristic]. The website is used as an (innovative) platform for this learning community.

Evaluation

The Wide River Project was initially evaluated in more detail than the other projects. In two pilot studies intensive observations, students’ products and students and teachers interviews were analysed and used to establish ‘were teachers and students had difficulty and what parts of the curriculum were missing’ (Rivet et al., 2000, p.11). This resulted in the acknowledgement that a need-to know-approach is not easy to establish. The authors of ‘the evolution of water, designing and developing effective curricula’ report that both teachers and students loose sight of the ‘driving question’ as the project evolves. Their activities become ‘de-contextualised’ as they call it:

“Data from students artefacts and interviews indicated that students did not see a connection between the content presented in the class and the context of the water quality project.”

(Rivet et al., 2000, p15)

The developers adjusted the content and content sequence and introduced what they called anchoring events and experiences, thus trying to strengthen the connection between content and context from the students’ point of view. They have not reported if and to what extend this has been successful.

3.3 Concluding remarks

Our study of a selection of innovative projects, of which we discussed two here, shows that all these projects can be interpreted as attempts to give content to the three characteristics of meaningful: a context, a need-to-know-approach and a attention for students’ input characteristic. We will now adopt these characteristics, at least tentatively, as essential ingredients of a *general framework for design of meaningful chemistry (and science) education.*

Moreover, in the discussed projects, the ‘need-to-know’ and ‘students feel that their input matters’ characteristics, seem to be inspired by ideas which are rooted in learning theories. In fact, all projects refer to such ideas, which are considered neglected in traditional science and chemistry education, for example: students should be actively involved in the learning process and there should be more attention for the student’s position, ideas and motives for learning.
The context characteristic seems to be generally rooted in the idea that a more authentic picture of science should be created, sometimes the projects refer also here to ideas from learning theories. This characteristic seems to range from ‘elaborating on the stories of the major ideas in science’ (Salters’ approach, thereby referring to Bruner) to ‘imitating roles of an existing chemistry practice’ (Chemistry in Products, thereby referring to Vygotsky and Leonte’v) and ‘being engaged in investigations through inquiry’ (Wide River Project).

By giving the three characteristics of meaningful the status of essential ingredients of a general framework for design of meaningful science education, we do not mean to suggest that those characteristics are new or revolutionary. In fact, most of them are almost obvious. In adopting the framework, we merely explicitly underwrite the sorts of potential solutions for some problematic features of science education. The general framework as such or the learning theories they may be rooted in, therefore, is not *primarily* our object of research. In the first instance, we think, the main problems do not consist in a better or sharper formulation of the framework. We think the main problems primarily concern the quality with which the framework is given content.

And, of course, as a consequence, a better and sharper formulation of the framework might very well evolve.
Firstly, the framework does not provide for distinct design principles, it merely provides for rather general directions for designing a teaching learning process. Secondly, in the innovative projects it is hardly evaluated to what extent meaningful chemistry, physics or science education has actually been realised *in relation* to the detailed designed teaching learning process. In the very few cases in which this does happen, it merely results in an acknowledgement that the characteristics of meaningful are difficult to *really* establish. For example, in the Wide River project it was initially found that students lose track of the driving question. This led to the notion that a need-to-know approach is difficult to realise, and although ‘anchor lessons’ were implemented, it did not lead to a fundamental rethinking of the need-to-know characteristic in the design. To conclude: giving content to the three characteristics in a design with sufficient quality and depth seems to be an important, but rather neglected and underestimated field of research. It is a kind of research, moreover, that in our opinion ought to precede or at least inform further theorizing, e.g. a better or sharper formulation of the general framework (see also Lijnse, 2001).

Our general research question might now be formulated as:

How to design a teaching-learning process by means of secondary science education modules, which properly embodies the three characteristics of meaningful?

4 Giving content to the three characteristics with sufficient quality and depth.

In this section, we will elaborate on the consequences of our aim to give content to the three characteristics in a design with sufficient quality and depth. We will show, in section 4.1, how this leads to questions that differ from the ones addressed in projects like the ones discussed in section 3.2. We will also argue that in order to properly address these questions, a specific research strategy called developmental research is needed. Next, in section 4.2, we will illustrate, using experiences with the design and development of the module central to this research, how this specific strategy of developmental research leads to findings that, again, are different from the ones in other projects. We will also illustrate how both such empirical evidence and theoretical reflections have led to a rethinking of the specific design and also to a rethinking of the general framework of meaningful.
Within the scope of this paper, our aim is only to give an impression of the potential of the research area identified above, in terms of the *kind* of questions asked, the *kind* of research conducted and the *kind* of findings all this have led to. No detailed analyses will be given.

4.1 Type of questions and research strategy

As we mentioned, research concerning projects like the ones described in section 3.2 generally focuses on the evaluation of larger scale characteristics of the designs. They address questions such as ‘what are suitable contexts (which, for example, both give rise to certain content and appeal to students)’, ‘what are the learning effects of the new approach?' or questions which concern implementation: 'how to involve teachers?' These type of questions are mostly addressed with what can be described as quantitative research, using for example pre- and post-tests, involving control groups, large scale interviews and means as questionnaires etc. Some projects do focus on the teaching-learning process. However, their object of research is rarely the relation between the realised teaching learning process and *the design*. They focus on things like 'motivation' or 'quality of argumentation'. The designs involved are merely described in broad outlines and play a subservient role (e.g.: Banet et al., 1997; Patronis, 1999; Roth 1993). Research that addresses in some detail the relation between teacher-student interaction and student input (related to the third characteristic), generally only concerns traditional chemistry or science education (Lemke, 1990; Edward & Mercer etc.).

If 'giving content to the three characteristics in a design with certain quality and depth' is object of research, this leads to a different type of questions. For then such questions as the following become relevant: do students really know what they do and why they do it every step of the way? (which should be an implication of the second characteristic), and do they feel that their input matters? in relation to the designed teaching learning process' (third characteristic). If one wants to get a deeper insight in *these* questions, then the focus of research must be on the teaching-learning *process*. This asks for a specific research strategy in which the teaching-learning process is followed in detail. In order to establish if the aims of the design are achieved in the teaching-learning process, a so-called 'scenario' is used, which gives argued expectations about what will happen at every step of the designed teaching-learning process (cf. Klaassen, 1995). It forms the framework for the interpretation of the realised teaching-learning process. Discrepancies between the intended and realised teaching learning process are considered indications for further research. These discrepancies are interpreted using not only the empirical evidence derived from experiments with the designed teaching-learning activities, but sometimes also theoretical insights derived from literature and maybe findings with similar experiments described in the literature (see section 4.2). All this can lead to adjustments in the design, scenario and sometimes the assumptions underlying the design. Such adjustments are of course hypothetical to a certain extend and need to be tested in a next round of experiments. And so on. The process of developmental research has therefore an interpretative, qualitative character.

In order to be able to focus in detail on the design and development of the teaching-learning process, we have decided to make just one module the object of our research, a brief description of which will be given in section 4.2. In section 5 we will discuss how we think this strategy, although it involves one module, leads to more general hypotheses about what could be features of meaningful chemistry education.

4.2 Design features and type of findings

Before we will go into the type of findings with this research, we will first very briefly describe how we have incorporated the three characteristics of meaningful in the initial design of our module. We will also very briefly describe the setting of the experiments.

Design features

The module is intended for 14-15 year old pre-A level students. Its first version was designed around a framework of driving question 'Is the water of our neighbourhood clean enough?' [first characteristic] and sub-questions carefully derived from this driving question (inspired by Rivet et al., 2000). This was mainly done by putting oneself in the position of the students, and formulating questions students would likely need and like to know in order to be able to answer the driving question [second characteristic]. This led to sub-questions like: 'What is the water used for? What are relevant parameters and norms? How can we test these parameters? How accurate are the tests? What are the test results?'. Answers to the sub questions would finally lead to an answer of the driving question: 'Is the water of our neighbourhood clean enough?'. At certain points students were to find answers by going into 'how it is done in reality'. The third characteristic, 'students feel that their input matters', was expected to be captured in the fact that each group worked on 'its own water', and that they were to present their findings for their classmates. The teacher was expected to guide this process. Moreover, each presentation (to be seen as 'student input') was to contribute to the insight that there is 'a common procedure' for testing the quality of waters with different functions.
The module constituted of eight lessons and should finally lead to formulation of a criteria based and well-founded judgement about the water quality.

Experiments

The first version of the module was put into practice at two different schools concerning three different teachers and their classes. Every step of the realised teaching-learning process was observed and followed in detail and compared to well-founded expectations of the intended teaching-learning process. Data concerned field notes, taped class discussions, work sheets, questionnaires and evaluative interviews. The overall research question was: how (if) and to what extend has meaningful chemistry education in this case been realised?
On the basis of the findings with the first version, some of which will be presented below, a second version was designed, in which in our opinion the three characteristics of meaningful would be better realised. This second version was put into practice the next year, with the same three teachers. Some of the findings with this second version are also briefly mentioned below.
Recently the third version of the module has been put into practice at two different schools, involving two different teachers. A thorough analysis of the data has yet to be made.

Establishing a relevant context

Students were highly interested in the project and the driving question of the module about water quality: 'Is the water of our neighbourhood clean enough?' In general, they worked enthusiastically and purposeful.

Establishing what could be interesting and challenging themes, story lines or driving questions for students, in general doesn't seem to be the major problem.
Schwarz reports of enthusiastic responses of students to Chemistry in Context (Schwartz, 1999). Studies show that students were motivated by the themes addressed in the story lines of Salter's approach (Campbell et al., 1994). Moreover the designers of 'The evolution of water' reported that students were in fact very motivated by the project, in which they investigated the water quality of 'their' river (Rivet et al, 2000).
Our first conclusion was that to properly realise the 'context' was not the main problem. This first instance, the major problems seemed to lie elsewhere.

A need – to –know approach

The module about water quality was designed with the idea that the sub-questions, derived from the relevant and motivating driving question, would embody a 'need-to-know' approach leading to the meaningful integration of content and context. But as it turned out, students did not integrate the concepts they addressed in for example the section 'principles and accuracy of test method' in the context of the driving question). They just did the section, and did it well without complaining, and never thought about it again. Students had not *really* experienced the relevance of quite a lot of the sub-questions and therefore the content involved. The sub-questions, which framed the sequence of learning activities had not emerged from their own experiences. Nevertheless, they were highly motivated and actively involved. If the whole teaching-learning process had not been observed in detail this probably would have stayed unnoticed.

Only two of the projects we studied reported experiences that can be interpreted as concerning the need-to-know approach, and in these cases the findings are in line with the experiences described above. Studies on PLON (not discussed here) show that the themes 'Traffic and Safety' and 'Ionising Radiance' did not solve well-known learning problems in classical mechanics and radiation and did not contribute significantly to the development of certain conceptions with students (Van Genderen, (1998) Eijkelhof, (1990). This seem to indicate that the themes function too much as 'appetisers' for content and a meaningful need-to-know connection between context and content was not established from the students' perspective. Above, in section 3.2, we described similar experiences with the Wide River project, were students in the process seem to lose track of the driving question and content becomes 'de-contextualized' from the students' perspective.

What could be learned from these experiences? The sub-questions, concerning what content the students 'need-to-know' in order to do their projects, had carefully been thought out and were expected to use and built on prior experiences and knowledge of students. Had these expectations been so entirely wrong? Of course: students had enjoyed the projects, but it still wasn't meaningful to them.
The problem was that *we* had felt that the students 'needed to know' about accuracy and reliability of the test methods, *they* didn't. These ideas had precisely been introduced at what we had considered 'the appropriate time'. Students *were told* what ideas and concepts they needed, and the expectation was that in the light of the driving

question they would see the logic of it almost automatically. We thought *our* aim (for students to get a deeper insight in accuracy and reliability of the test methods in order to arrive at a reliable judgement of water quality) was *their* aim. And that is where things went wrong: we never really paid attention to the motives of the students. What were their aims anyway? Probably mostly 'doing the right thing and being a good learner'. This explains why they 'did' the section about accuracy and reliability neatly and without asking questions, although they did not see the point.

At one point, when a group of students presented and discussed their findings with the class, the sub-question 'how accurate are these tests?', *did* emerge from their experiences and became relevant. These students had a test result, just within the norm. They judged their swimming water as 'good' and a discussion arose if you really could conclude this in view of the accuracy of the tests. The discussion finally led to the conclusion that you should not take the *risk,* because you can't be sure that the *real* value of this parameter is safe. Finally 'the accuracy of the test method' had become a meaningful topic.

We concluded that learning activities should be designed in such a way that they give rise to specific questions with students, this way inducing a 'knowledge need' in a certain direction (f.e. about the 'accuracy of the tests), rather then posing a sub-question which is then answered in (a series of) learning activities as we did in the first version of the design (cf. Klaassen, 1995, who referred to this as the development of 'content related motives' with students).

This led to the more specific question, of which we hope to have illustrated the highly non-trivial nature: how can a sequence of learning activities raise questions with students (content-related motives), with which they can identify and which also lead them to the (top down formulated) learning goals?

Attention for students input

When the second version of the water quality module was put into practice another problem became apparent. We had paid specific attention to the need –to –know characteristic in this version. The successive learning activities were now more or less designed in such a way that a specific 'knowledge need' raised in one learning activity was elaborated upon in the next, which at the same time induced a second 'knowledge need' and so on. Although this characteristic still needed more rethinking (see f.e. 'sharpening of the framework of meaningful'), in the second experiment, the students seemed to appreciate the logic of the unfolding learning activities most of the time, that is, when the teachers paid serious attention to their input. The problem now was that two of the teachers involved tended to ignore the input of students. They had not been sufficiently prepared for the fact that the input of students was an important driving force in the designed teaching learning process. Let alone that they were sufficiently prepared for *how* such a process should be guided. The teachers relied on their own teaching style. And in line with Lemke's findings these were dominated by dialogues in the classroom with, what Lemke described as, a 'triadic dialogue structure' (Lemke, 1990) (cf. section2) (see also Rop, Watts and Carr: how difficult it is for a teacher to question differently). Also, at frequent times these teachers used the content as a means to control the class. As a result the motivation to get a deeper insight in certain content shifted from 'wanting to know in the light of the driving question' (content related motives) to 'important for the test'. The students of these teachers hardly appreciated the logic of the learning activities. Whereas the students of the third teacher involved, who did appreciate the students input much more, were much more involved in the logical unfolding of the learning activities.

We concluded that the idea of letting student test 'their own' water and present their own results seemed not strong enough to secure that students feel that their input matters. This characteristic needed a much more detailed approach, on the level of interactions between teachers and students.

Again, a more specific question was raised, of which again we hope to have indicated the non-triviality: (for each learning activity) what interaction structure between teachers and students promotes (in this specific learning activity) that students feel that their input matters? And: how to implement such interaction structures in the teaching-learning process?

Sharpening of the framework of meaningful chemistry education

After the experiment with the second version of the design we reconsidered our interpretation of context. Until then, we had interpreted context in line with the Wide River project as a driving question, which is related to the need-to-know characteristic in the sense that it should give rise to sub-questions considered relevant by students. When viewed in isolation, the way we had given content to the 'context' characteristic, seemed to be properly realized, in the sense that students were interested in the driving question and were generally motivated by it. When viewed in relation to the need-to-know characteristic (by means of sub-questions), however, we began to doubt this conclusion, as students did not identify with the questions raised. As described in the previous section, the problem was how to secure that sub-questions (that were to lead to certain desired (by us) content) would *really* reflect motives and aims of students. The idea of creating content related motives through learning activities had helped in the sense that sub-questions in the second version were increasingly raised by *students*. Still we felt that the problem was not sufficiently solved yet. The idea of a driving question simply seemed not 'strong' enough, in the sense that it did not sufficiently help to define *which* sub-questions (although now more raised through learning activities by student themselves) are relevant for students at certain points in the teaching learning process. Such theoretical considerations led to our rethinking of the framework of meaningful, and in particular of the connection between the context and need-to-know characteristic. Partly inspired by Van Oers' and Van Aalsvoort's interpretations of the concept 'context', we have come to think of it now as a 'communal enterprise or practice'. The idea is that such a practice involves a central activity with distinct purposes and aims and connected roles for students and interaction structures, which pay attention to the input of students. All this, the practice as a whole, is in our opinion the context in which students learn chemistry. As a consequence, the students' appreciation of the purposes and aims of the practice forms a necessary condition for their learning process. And in order to effectively perform actions in such a practice they will need certain relevant content. We refer to such a practice in which students should get increasingly involved as an 'educational practice' (Bulte et al., 2002).

The idea of establishing an appropriate educational practice has led to a sharpening of the general framework of meaningful, because it raises the questions what characterizes an appropriate practice and how can it be established? Without pretending to give full answers here, we make some suggestions. We think a first criterion is that an educational practice should have close relations with an existing chemical practice. Secondly, we think that it should provide students with certain roles with which they can identify. This will increase their involvement. For then, the existing practice can provide the educational practice with a characteristic procedure, and provide students, while playing their role in the educational practice, with relevant and recognisable information. Thirdly, we think that students should already know this procedure, at least in some rudimentary form. Because then, this procedure will 'tell' them so to say what the next logical step in the process will be.

By beginning to think about the 'context' characteristic in this way, we were for example in retrospect able to notice an inconsistency in the second version of our module, which led to some confusion among students we did not understand in our earlier analysis. It was due, we now think, to our mixing up two different practices, (and their connected sets of purposes and aims): 'testing and judging water quality' and 'producing drink water quality'.

The design of the third version of our module can be seen as guided by this renewed general framework of meaningful. In broad outlines it is as follows. Since the aim of testing and judging water quality concerns such basic human needs as clear drink water or swim water we expect that students consider it worthwhile to find out what is involved in deciding if water quality is 'good enough' for a certain purpose. To find that out (what is involved), an educational practice is set up by given them real water samples derived from real situations in which judging water quality plays a central role. The purpose of the educational practice is now established: to gain knowledge about what is involved in deciding if water quality is good enough for a certain purpose, and students are asked to play their role in this educational practice. All this is expected to provide them with a clearly defined motive: what do we need to know to be able to come a decision? Students do posses, in our opinion, a sense of the steps involved in the procedure to arrive at such a decision (testing and judging quality) but they lack certain specific chemical knowledge. The art is to use this intuitive knowledge of students concerning the procedure and in particular their appreciation of the logic of the successive procedural steps (which might have a different sequence than in the chemical practice it was derived from) in the design of learning activities. This must be done in such a way that students stumble on what they do not know but need to know in order to take the next step in the procedure and finally arrive at a decision. They are, for example, very much aware that water can contain all kinds of stuff which might be bad for you if you would drink it and that it would be a logical step to test the water to see if its safe to drink. However, they do not know *what* things would be relevant to test. At this point, students can derive the relevant information from the existing practice: what is tested in reality? Also, they do sense the need to compare your test results with something, and by doing this they *become aware* of the question '*how much* is allowed of these things in drink water?'. Again, the existing practice provides students with information about how it is done in reality. Then such questions can be raised with students as: why is it done like this in reality? Why for example is the water tested for these specific things? Eventually in interplay between the existing chemical practice and the evolving educational practice the procedure is expected to be made more and more explicit by students, continually driven by motives of students to set the next step in the educational practice.

The third version has recently put into practice with two new teachers at two new schools. Data has not been analysed yet, but preliminary results indicate that students are motivated to know more about what is involved in the practice of testing and judging water quality. They also seem to experience the logic and usefulness of the successive learning activities, which now induce content related motives by using the intuitive notions of students of 'the next step of the procedure'. Students seem to act as we expected (described in the scenario). The successive learning activities do seem to lead, for example, to students raising the questions we expected (f.e. what is tested in reality?, how much is allowed of these things in drink water? Why are these things tested? Why not different things or more things? etc.). Also evaluative interviews seem to point at an appreciation of students of the logic and usefulness of the learning activities.
In summary, the tentative results indicate that the design seems to make adequate use of the intuitive notions of students about the central procedure and the teachers were much better prepared for their role.

5 Conclusions and discussion

We showed that, if the aim is to involve students in the learning of chemistry the problematic features of chemistry education should be addressed: rhetoric of conclusions, inconsistencies and a lack of students input. This led to the identification of the three characteristics of meaningful: a context, need-to-know and a 'students feel that their input matters' characteristic. It was argued that to comprehend the scope and depth of 'properly' in the question '*How to design a teaching learning process in secondary science education modules, which properly embodies the three characteristics of meaningful?'*, a detailed intensive study of the teaching-learning process is necessary. We showed how this, in our opinion underestimated area of research, led in this case to a rethinking of the framework of meaningful.
The questions remains, to what extend can the intended research results of one case study concerning one module be useful for other modules?
When one module is object of research, of course, conclusions about how (if) and to what extend meaningful chemistry education has been realised are situated. They primarily refer to the design and development of this one particular module put into practice in a limited number of classes involving a limited number of teachers. Fensham criticised the situated ness of science and chemistry education research (Fensham, 1999). His arguments were that concepts in science (or chemistry) education have led to isolated studies on isolated concepts, mostly focussing on so-called 'alternative conceptions'. He stresses that it is time to pay attention to the science or chemistry[3] content as problematic and that research should lead to consequences on curriculum level. In our opinion, our research is different than the

[3] Fensham refers to research in science, physics and chemistry education

studies Fensham refers to, in the sense that it does not focus on a specific concept and how to design teaching learning strategies to address learning problems connected to specific concepts. In the module, concepts will be introduced only when relevant within the context (namely the educational practice) to be established and as a consequence, not only the embedding of the content, but also the content itself, which could be different from traditional content. Finally, the problematic features 'rhetoric of conclusions', 'inconsistencies' and 'lack of students input' can on curriculum level be interpreted in terms of 'a not properly worked out framework of meaningful chemistry education'.

To conclude, we expect that, if for this case meaningful chemistry education can be established, it will contribute to more specific design directions for other modules than the directions we tried to derive from projects described in section 3. In fact, our group is doing exactly that (f.e. Bulte, 2003). Of course, although the framework of meaningful evolves, it does not provide for algorithmic decisions, which you only have to 'execute' to end up with a meaningful teaching learning process. The framework should merely serve as a specified heuristic scheme of steps and criteria for decisions. In practice this means that for every design a detailed, situation specific and intensive study of the teaching-learning process is needed to establish if, how and to what extent meaningful chemistry education has been realised.

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