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## Providing Students with a Sense of Purpose by Adapting a Professional Practice

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► **To cite this version:**

Hanna B. Westbroek, Kees Klaassen, Astrid Bulte, Albert Pilot. Providing Students with a Sense of Purpose by Adapting a Professional Practice. *International Journal of Science Education*, 2010, 32 (05), pp.603-627. 10.1080/09500690902721699 . hal-00568408

**HAL Id: hal-00568408**

**<https://hal.science/hal-00568408>**

Submitted on 23 Feb 2011

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|------------------|---|
| Journal:         | <i>International Journal of Science Education</i>                         |
| Manuscript ID:   | TSed-2008-0176.R1   |
| Manuscript Type: | Research Paper  |
| Keywords:        | design study, science education, developmental research, secondary school |
| Keywords (user): | meaningful, advance organizer, professional practice                      |
|                  |   |



# Providing Students with a Sense of Purpose by Adapting a Professional Practice

## Introduction

This article presents the findings of a design study that addressed the problem that Gunstone (1992) has put as follows: ‘This problem of students not knowing the purpose(s) of what they are doing, even when they have been told, is perfectly familiar to any of us who have spent time teaching. The real issue is why the problem is so common and why it is so very hard to avoid’ (p.131). The problem of students not knowing the purpose(s) of what they are doing and learning is widely recognised in chemistry education. The curriculum has become overburdened with isolated facts detached from their scientific origin. Students then find it hard to give meaning to chemical content and to apply what they have learned.

A now broadly applied strategy to provide meaning to chemical content is the use of contexts as a starting point for introducing chemical concepts (Gilbert, 2006). This strategy was also adopted by the committee in charge of the revision of the Dutch chemistry curriculum (Driessen & Meinema 2003). The committee expected that ‘the social, professional and theoretical contexts will appeal to students and serve as a bridge between the real world and the chemical concepts that underpin the subject’ (p.7). In fact, although the conceptualization of contexts differs (e.g. Gilbert, 2006), this assumption basically underlies all context-based projects: contexts help students to see the meaning of the concepts involved. In some cases a theme or a storyline is used for this purpose (Bennett & Holman, 2002; Lijnse, Kortland, Eijkelhof, Van Genderen & Hooymayers, 1990; Millar, 2006; Parchmann et al., 2006).

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In other cases the context is formed by a central question that students need to answer by means of a series of connected sub-questions in a project-based approach (Rivet, Singer, Schneider, Krajcik & Marx, 2000; Schwartz & Crawford, 2004).

In spite of such aims, different studies report that it is not easy to actually achieve that students experience a meaningful connection between the context and what they learn (Kortland, 2005; Rivet et al., 2000; Singer, Marx, Krajcik & Clay-Chambers, 2000). What is needed is that students are able to see beforehand, for each of their activities in class, what this is going to contribute to a specific context-based purpose they want to achieve (Author, 1995; Lijnse, 2005).

In this article we explain how we have attempted to realise such a sense of purpose in the design of a chemical teaching sequence by adapting a science-related practice. We will present our main findings and conclusions concerning the evaluation of the teaching sequence.

### **Theoretical framework**

In our approach we aimed to make each of the students' classroom activities meaningful to them. In general, what makes an activity meaningful to someone is that he or she has a reason or motive for it. That is: an answer to the question 'Why am I doing this?'. A motive for an activity minimally requires a desire and a belief. First of all, one needs to have a desire for a certain state of affairs, a certain overarching goal. Secondly, one needs the means-end belief that the activity will contribute to attaining that state of affairs. From such a belief-desire combination it follows that there is something attractive in performing the activity. So if we want to make students work purposefully on a task, we must enable them to see in advance what the task at hand promises to contribute to achieving which purpose. It requires that students both want

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to realize certain goals and are able to conceptualize the process towards reaching those goals as an ordered set of instrumental activities. Of course, students can have (and typically do have) other motives for performing learning activities, such as pleasing the teacher or getting a good grade. The focus of this paper, however, lies particularly on the development of content-based motives in the design of a teaching learning process (Author, 1995).

These above requirements very much amount to what is widely recognized as a basic principle behind all good science teaching:

- To give students clear objectives for what they are going to do.
- To make sure that students have the necessary concepts and techniques in place and ready for use.

What our approach adds to this basic principle is explicit attention to balancing the student perspective with the aims of the course designer. This requires making a distinction between learner's goals and attainment targets. The learner's goals should be worthwhile to him or her in advance of being aware of the knowledge and abilities aimed at by the course designer. Students should be able to see that work as instrumental in reaching their objectives. At the same time, their work should also bring them closer to the attainment targets aimed at by the course designer. It is a difficult challenge for the course designer to meet all these requirements. Hence the reason why the problem pointed out by Gunstone (1992) is so very hard to avoid.

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*Advance organizers that integrate motivational and cognitive functions*

The aim of this study was to find and exploit appropriate means to enable students to conceptualize their learning process in advance as an ordered set of activities geared at

1  
2 reaching worthwhile goals. This can be compared to what Ausubel (1968) advocates as  
3 the principal strategy for 'so shaping the learner's cognitive structure [...] that  
4 subsequent learning experiences are maximally facilitated' (p. 147-148), namely the  
5 use of advance organizers. 'These organizers are introduced in advance of the learning  
6 material itself and are also presented at a higher level of abstraction, generality, and  
7 inclusiveness. Since the substantive content of a given organizer or series of organizers  
8 is selected based on the appropriateness for explaining, integrating, and interrelating the  
9 material it precedes, this strategy simultaneously satisfies the substantive as well as the  
10 programming criteria [...] for enhancing the organizational strength of cognitive  
11 structure' (p. 148).

12  
13 Ausubel emphasizes the *cognitive function of an advance organizer*. We wanted an  
14 *advance organizer to have an additional motivational function*. It should provide  
15 students with content-based motives for participation in a learning process by  
16 conceptualizing the process as a viable route to their objectives.

**Deleted:** 'to provide ideational scaffolding for the stable incorporation and retention of the more detailed and differentiated material that follows in the learning passage' (p.148)

**Deleted:** (see also: Author, in press)

### 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 *Professional practices as sources for advance organizers*

33 In order to provide students with a sense of purpose, our starting point was to establish  
34 functional means-end relationships. What students are going to do in class should be  
35 perceived by them as functional for obtaining their objective (Author, 2005a). When it  
36 comes to designing a teaching-learning process, this starting point as such gives little  
37 guidance. It merely emphasizes the need to identify a suitable advance organizer to  
38 elaborate on in a series of teaching-learning activities. The real educational challenge  
39 lies in working this out with sufficient quality.

40 In science education the idea of an advance organizer has generally been interpreted  
41 as an organizational cognitive framework, e.g. concept maps, which the teacher  
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2 presents to students prior to teaching them new content (Mayer, 2003). Without  
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4 wanting to argue about the value of such formats for other purposes, we do not consider  
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6 them as particularly suited for integrating the cognitive and motivational functions that  
7  
8 we envision. In this study we explored the possibility of using a science-related practice  
9  
10 as a source for advance organizers that integrate motivational and cognitive functions.

**Deleted:** Commonly used formats are analogies or concept maps (Woolfolk, 2001).

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12 This approach was inspired by the work of Van Aalsvoort (2004) (see also Author,  
13  
14 2005a; 2005b; Author, 2006).

**Deleted:** From now on, if we discuss the idea of an advance organiser, we refer to advance organisers that do integrate both functions.

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16 In a professional practice, professionals more or less know how the activities they  
17  
18 perform will contribute to the purpose they want to achieve. We expected that this  
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20 structure of means-end relationships could be adapted to yield advance organizers for  
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22 educational use, if at least two conditions are met. First, students should value the  
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24 purpose of the practice. If so, they can become interested to learn about how people  
25  
26 achieve this purpose. Secondly, students should have rudimentary knowledge of the  
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28 procedures and ways of (scientific) thinking that are employed in the professional  
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30 practice. When properly worked out in a teaching-learning process, the prior knowledge  
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32 in combination with the goal to learn about the professional practice can function as an  
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34 advance organizer.

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36 For the case of monitoring water quality, the practice discussed in this paper, students  
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38 for example know that the water needs to be tested. But they do not know for what  
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40 substances and how. In the activities that follow, the practice can serve as a source of  
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42 information for what is to be tested. Also more detailed questions may arise that  
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44 students feel need to be answered in order to be able to complete the procedure: these  
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46 questions should be answered in new, additional steps.

**Deleted:** It is possible that students intuitively appreciate that some steps need to be taken, but lack the specific knowledge to be able to actually take these steps. In

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48 We want to emphasize at this point that the course designer will have to  
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50 purposefully deviate from the professional practice in order to secure that the learning  
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**Deleted:** The previous paragraphs may suffice to make plausible the idea of using a science-related practice as a source for advance organizers.

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2 activities remain purposeful to students. For example students will not be able to  
3 conceptualize the goals and direction to follow in the same fullness and depth as the  
4 professionals of that practice. Below we address and discuss further aspects of adapting  
5 a professional practice for educational purposes. We will also return to this issue in the  
6 conclusive section.  
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### 13 **Research question and research strategy**

14 Our aim was to further explore the idea of identifying and elaborating an advance  
15 organizer in the design of an instructional version of a professional practice. We took  
16 this aim to involve at least the design of a proof of principle: is it possible at all?  
17 According to Freudenthal (1991) a proof of principle involves two things. In the first  
18 place it involves showing that the idea can be worked out by designing at least one unit  
19 in such a way that is convincing in itself. Secondly, it involves proving that the  
20 intended teaching-learning process can be implemented with sufficient quality, that is:  
21 meeting the aims and expectations of the designers. The research question answered in  
22 the present paper corresponds to the aim to deliver such a proof of principle:  
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34 *Is it possible to provide students with a sense of purpose by establishing functional*  
35 *means-end relationships in an instructional version of a professional practice?*  
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40 Besides delivering a proof of principle, there is the need to address the broader  
41 applicability of the design principle: what makes it possible? This point is of a more  
42 theoretical nature, and comes down to identifying and clarifying key issues that are  
43 involved in transforming a professional practice into an adequate instructional version.  
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48 We briefly discuss some of those key issues in the conclusion.  
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### *Research strategy*

Exploring the usefulness and consequences of theoretical ideas by working them out in a teaching-learning process is at the heart of developmental research or design research (Cobb, Confrey, diSessa, Leherer & Schauble, 2003; Gravemeijer, 1998; Lijnse, 2005).

The teaching-learning process is optimized in several research cycles, focused on testing, reflecting on and adjusting the designed teaching-learning activities. Testing the designed teaching-learning process takes place in a small-scale case study, with a classroom and its teacher as the unit of analysis (Cobb, Stephan, McClain, & Gravemeijer, 2001). The design is accompanied by a set of argued expectations of how the unit is expected to function. Such expectations are based on evidence from the literature as well as research findings from earlier research cycles.

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The design presented here is informed by empirical evidence from two previous research cycles that each involved three teachers from two different schools and their classes. The idea to adapt a science-related practice emerged from these previous research cycles (Author, 2005a).

To be able to determine whether the design was indeed a proof of principle, we first explain and justify which elements of the design we expected would provide students with a sense of purpose. Next, we discuss the evaluation of the design: the method used and the results obtained. For this we divided the research question into four main evaluative questions connected to the main elements of the design (see Table 3).

### **Design of an instructional version of the practice of monitoring water quality**

The professional practice, the learners' goals and expected learning outcome are presented in this section. How the advance organizer was expected to be evoked is

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described in the sections ‘Achieving that students value the purpose of the instructional version’ and ‘Letting students explicate their rudimentary knowledge’, after which an overview of the whole unit is given.

### *The practice of monitoring water quality*

Practices that monitor water quality were analysed by means of a literature study and interviews with participants. The practices varied from monitoring the water quality of swimming water to monitoring drinking-water quality. The interviews were also used to collect a series of real case-descriptions for introducing the instructional version of the practice.

The various practices of monitoring water quality took place according to one and the same procedure, as represented in Figure 1.

**[Insert Figure 1 about here]**

Identifying the water function and establishing the relevant parameters and norms are often fixed steps in a given practice. The tests usually follow standardized procedures and may be fully automated. Just a small selection of parameters is typically monitored. When the test results for those parameters fall well within the norms, this indicates that the quality is sufficient. If some norms are exceeded, they together give a good indication of what might be wrong. The participants of the practice have background knowledge about the selection of parameters to be monitored, about the implications of a parameter exceeding the norm, and so on. They usually report their findings in a standardized format.

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*Purpose and intended learning outcome of the instructional version*

The purpose of the instructional version cannot coincide with the professional practice's purpose, because students are not to deliver an authoritative report on the quality of a particular type of water. Rather, we wanted their purpose to become, 'finding out how water quality is monitored'. This they are to do by simulating the professional practice, at least to some extent. The extent to which the professional practice is simulated, and what students are to learn, is determined by the ability level and age of the students (14-15 year old, O-level), by the total time available (four 50-minute and two 75-minute lessons), and by the resources available.

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We aimed at the following attainment targets.

- Explicit knowledge about the procedure (Figure 1).
- Knowledge of the argumentation behind the lists of chemical, biological and physical parameters and norms.
- Insight in the reasons for selecting a limited set of parameters to be monitored (in the case of drinking-water quality: chloride, nitrite, pH and E-coli). This does not involve in depth knowledge about the chemical processes involved, but rather on the level of: 'the pH is easily influenced in the presence of other substances'.
- Knowledge of the basic principle of colorimetric tests. Insight in the chemical processes behind these tests was not part of the attainment targets.
- Basic insight in the concepts of accuracy and reliability and explicit awareness of the relevance of these concepts in the context of quality assessments.

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Deleted: We also wanted students to learn that for each water use there is a long

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Deleted: inclusion of those parameters with those norms. Students were to learn that only a

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Deleted: , and why this short list suffices for practical purposes (even though some highly poisonous parameters from the long list are not tested).

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Students used simple 'black box' Merck-kit tests, which are indirect colorimetric tests.

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**Deleted:** did perform tests, but not with the apparatus used in the professional practice. Instead, students

For example: the more nitrite the water sample contains, the more intense the colour that emerges after treatment. After treatment, the coloured solutions that emerge are compared to a standard calibration series. For E-coli, students used a very simple standard test. Part of the water sample was incubated overnight using a specific medium. The colour of the sample changes when E-coli exceed the norm (10 colonies per litre). Based on experiences in previous research cycles, we expected that performing tests with rather primitive means would make students unsure of their own performance and of the spread in their test results, thus providing an opportunity to directly introduce the notions of accuracy and reliability.

**Deleted:** A learning goal related to the tests was explicit awareness of the relevance of the concepts of *accuracy* and *reliability* in the context of quality assessments. In this respect, we thought it useful that students had to perform the tests with rather primitive means.

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*Achieving that students value the purpose of the instructional version*

First, students had to be interested in finding out how water quality is monitored. To achieve this we presented them with a selection of genuine water samples from different settings. The selection represented a broad variety of cases, appealing to a range of basic needs, such as health, safety and sustainability. The description of each case ended with a question emphasizing the importance of monitoring water quality properly. For an overview of cases, see Table 1. Subsequently, students were asked how they thought the water quality is checked and whether they would think it worthwhile to find out about how this is done in chemistry class.

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**Deleted:** We expected that students would appreciate the relevance of the practice of monitoring water quality as it concerns such basic needs as clean and healthy drinking-water, ecologically healthy water and so on. At the beginning of the unit

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**Deleted:** how water quality is monitored

[insert Table 1 about here]

*Letting students explicate their rudimentary knowledge as an advance organizer*

Based on the previous two research cycles (Author, 2005a), we expected students to have the following rudimentary knowledge:

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With respect to conceptual knowledge,

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#### A. Conceptual knowledge.

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- Water can contain all sorts of substances that make it unsuitable for its intended use;
- There are tests to determine whether water contains certain substances and how much, even if these substances cannot be readily observed with our senses.

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#### B. Procedural knowledge.

**Deleted:** At the same time, this knowledge reveals gaps of which students are to become aware. For example: which polluting substances makes it unsuitable for which use?, and: what tests are there for which substances? ¶  
With respect to prior procedural knowledge, we expected students

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- The procedure outlined in Figure 1, though perhaps not fully complete and articulate;
- Additional information can be obtained from the professional practice;
- Following the procedure, and gaining the relevant information where needed, will lead to more detailed knowledge about how water quality is monitored.

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In view of their prior knowledge we expected that students would be able to come up with the following procedural steps and knowledge needs:

**Deleted:** In the first episode of the unit we tried to make students formulate a plan for their purpose. The students were asked how they thought the participants of the professional practice would go about monitoring water quality.

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#### Procedural steps.

- a. Determine the water function; this determines the quality criteria.
- b. Test the water sample: does the water quality meet the criteria?
- c. Compare the test results with an appropriate standard.

#### Knowledge needs.

1. Which polluting substances make the water unsuitable for which use?
2. What tests are there for which substances?
3. With what standards do we have to compare the test results?

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*The episodic storyline of the unit*

The unit was divided into several episodes (see Table 2). We described the first episode, the 'context-setting part', which sets the scene for what is to follow.

**Deleted:** In Table 2 it is therefore marked as the context-setting part.

Besides a context-setting part, there was a middle part and an evaluation part. For each part it is indicated separately how that part is functionally embedded in a broader purpose for the students (student function) and how for the teacher/designer (teacher function). Below we describe and explain in more detail the functions of each episode.

**Deleted:** what the student function is and what the teacher/designer function is. With this we wanted to distinguish between

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**[Insert Table 2 about here]**

For the students, the function of the context-setting part is to find out what it is about, whether they are interested in its purpose, and to formulate a plan for how to proceed.

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For the teacher or designer, the function is to facilitate all this by presenting well-chosen cases, asking students whether they are interested in finding out how such cases are solved and how they think this is done. The teacher is merely to summarize the students' opinions and ideas on how to proceed. Episode 1 takes about 25 minutes.

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Following the context-setting part is the middle part, covering most of the unit (about three 50 minute lessons and one 75 minute lesson). For the students, the function of this middle part is to carry out their rudimentary plan for the case of drinking-water quality, with the expectation to thus find out about the way water quality is monitored in general. Table 2 shows that the middle part consisted of six episodes, each more or less corresponding to a procedural step. Episodes 2 to 4 concerned the steps a to c made explicit in the context-setting part (see previous section). The teacher/designer function of these episodes is that students come to fill the gaps in their knowledge (1-3), partly by consulting the professional practice.

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<#>Find out which parameters are monitored when drinking-water quality is monitored¶  
<#>Find out how they themselves can measure these parameters.¶  
<#>Find out the appropriate standard to compare their test results to. ¶  
If the teaching-learning process unfolds as expected, the students should figure out themselves that this information can be obtained from the professional practice. The teacher is to coach students by confirming their expressed knowledge needs and by directing them in where to find information from the professional practice.

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4 A further teacher function of the middle part is that new knowledge gaps become  
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6 apparent. After doing the tests, students are expected to at least feel unsure about  
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8 making a final assessment of the water quality. We expected this on the following  
9  
10 grounds:

- 11 • The water quality tests concern only a small selection of four parameters:  
12 students do not know why these four are selected.
- 13 • Students are uncertain about their performances of the tests.
- 14 • The test results will show spreading.

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20 These sources of insecurity lead to additional steps, which are taken in episodes 5 and  
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22 6. In episode 5 students find out from the professional practice how and why the short  
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24 list of parameters is selected from a much longer list. We expected that an  
25  
26 understanding of the underlying reasons would solve the students' insecurities. In  
27  
28 episode 6 students reflect on their insecurities about how they performed the tests (e.g.  
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30 'we did not stir the solution for the full two minutes') by discussing possible  
31  
32 experiments that would test the quality of their performance and by carrying out these  
33  
34 experiments. We expected students to solve these particular insecurities in this way and  
35  
36 to become aware of the relevance of the concept of reliability. With respect to the  
37  
38 uncertainties about the accuracy of their results, students discuss and reflect on the  
39  
40 spread in their results. They are expected to base their decision on whether their results  
41  
42 are well enough within the norm, thus addressing their insecurities and learning about  
43  
44 (the relevance of) the concept of accuracy. When the uncertainties are resolved,  
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46 students are able to present their final assessment in a standardized report (Episode 7).

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49 The student function of episode 8 is to evaluate the unit as a whole, in light of their  
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51 purpose: find out how water quality is monitored. The teacher function of this episode  
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2 is that a general procedure for monitoring water quality comes to the fore. We expected  
3 students by now to intuitively appreciate that although the details may be different in  
4 the different sample cases, a similar procedure is applicable. In order to check these  
5 intuitions, students are asked to design a manual for a fellow student for another case,  
6 for example for swimming water.  
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11 Finally, the following aspect of the design we expected to be important for structuring  
12 the lessons for the students. In the context-setting part, students' ideas on how water  
13 quality is monitored are to be collected by the teacher and to be written down on a  
14 'procedure poster'. Every time students feel the need to refine a step or add a new one,  
15 the procedure on the poster is to be adjusted. This way, the students can continuously  
16 see how their plan evolves during the unfolding of the lessons.  
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Deleted: This poster is to remain at the front of the class during the lesson series.

26 Following the description of the design we divided the research question into four main  
27 evaluative questions and connected sub-questions (Table 3).  
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Deleted: Below we answer these questions.

31  
32 [insert Table 3 about here]  
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35

### 36 Method

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38 The design was put into practice in a regular school setting. The students involved were  
39 14-15 years old and doing O-level (academically streamed). The class contained 27  
40 students. The students worked in groups of three or four (a total of eight groups).  
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#### 46 *Teacher preparation trajectory*

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48 A special preparation trajectory was designed for the teacher. The teacher faced in  
49 particular the following challenges:  
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- Paying adequate attention to student input in order to ensure that students' ideas and rudimentary knowledge become an important driving force of the teaching-learning process.
- Following a storyline in which every episode builds on the previous one and prepares for the next.

The trajectory had two main features: practice by means of a 'try-out class' and directed feedback by means of video recordings (Joyce & Showers, 1980). The try-out class was only involved in the preparation of the teacher. Every lesson in the try-out class was video taped and discussed between the researcher (first author) and the teacher.

#### *Data collection and analysis*

Our aim was to provide a proof of principle. In order to deliver a proof of principle, it should be made evident that the expectations at the level of the evaluative sub-questions (see Table 3) were met, or *could* have been met. We concluded the latter in the following kind of cases. Students did experience the need to take a certain step; specific assignments turned out to not adequately meet these needs and, in retrospect, we understood why; based on this understanding we now know how to improve the assignments.

Different sources of information (written answers, class discussions, and post-interviews) were analysed and interpreted together to answer the questions in Table 3.

All the lessons were audio and video taped. Based on observations, fragments of the critical instances in relation to the evaluative questions were selected and transcribed verbatim by the first author to verify whether the teaching-learning process had

1  
2 unfolded as intended and expected. Additional data from written answers, a  
3 questionnaire and post-interviews were used for triangulation when necessary.  
4

5  
6 The result was a description of the teaching-learning process in terms of class  
7 discussions as fed by the outcomes of previous group discussions. Such a description at  
8 the class and group level suffices in our opinion to deliver a proof of principle. A  
9 detailed study of the small group discussions and of the learning processes of individual  
10 students would have added more relief and colour to the description, but would not  
11 have affected the main conclusions.  
12

13  
14 The first description of the process was verified by a second researcher (second  
15 author) and revised until consensus was reached on the findings. These 'thick'  
16 descriptions of the evaluation of the expectations were further discussed within the  
17 entire research team and adapted when necessary. Based on these descriptions the  
18 teaching-learning process was reconstructed and the evaluation questions answered.  
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### 30 Results

31 A detailed report of the results can be found in Author (2005a).  
32

33  
34 *Question 1: Did students explicate the expected advance organizer in the context-*  
35 *setting episode of the instructional version of the practice?*  
36

37  
38 The three sub-questions of question 1 are successively discussed below.  
39  
40  
41

42 *1A: Did students value the purpose of the instructional version of the practice?*  
43

44 Students discussed the following question in groups of four: 'Do you consider it  
45 interesting to find out in chemistry class how people do this? Yes, no, because...'.  
46  
47

48 [Group answers](#)  
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**Deleted:** Most students linked their learning on how people monitor water quality to outside-school values.

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2  
3 Basically two values were linked to the topic of monitoring water quality: a better  
4 environment (2 out of 8 groups) and health (3 groups).

**Deleted:** Two out of eight groups appeared to refer to the value 'a healthy environment'.¶

¶ Yes, because we are in favour of a better environment.¶

¶ Yes, life needs a lot of water. Water is the source of life.¶

¶ Three groups referred to 'health'.¶

¶ Yes, people can get sick if they swim in polluted water.¶

¶ Yes, because people drink it.¶

¶ Yes, it is also important for us, a lot of people get sick.

8 The remaining three groups just answered that they considered it important to find out  
9 about how people monitor water quality.

10 In a class discussion the values mentioned were generally appreciated.

**Deleted:** it turned out that also the students in these groups appreciated

**Deleted:** by the other groups

**Deleted:** rudimentary knowledge

14 Based on our findings we concluded that the answer to question 1A is 'Yes'.

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18 *1B: Did students explicate the procedural steps and their knowledge needs as*  
19 *expected?*

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22 Students discussed in groups the question 'How do you think it is monitored whether  
23 the water satisfies the criteria (what steps are involved)?'

**Deleted:** The students did explicate their rudimentary procedural and conceptual knowledge. When

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24  
25  
26 Group answers

27  
28 The following answers typically came up:

**Deleted:** their group answers reflected the step 'test water samples'.

**Deleted:** type of written

30  
31  
32 Test in a lab & by the swimming pool itself (chlorine). Take a sample; measure  
33 the temperature.

34  
35 Take samples and test them.

36  
37 Have a lab test the water regularly to see if the quality is still ok.

38  
39  
40 Measure the salt concentration; measure the temperature;

**Deleted:** One group's answer also reflected that students knew that drinking-water can contain all kinds of substances that might influence the water quality. ¶

41  
42  
43  
44 In the evaluative class discussion the three procedural steps could easily be triggered.

**Deleted:** Measure the salt concentration; measure the temperature; determine whether the temperature and the salt concentration are constant.¶

45  
46 The teacher wrote the students' answers on the 'procedure poster': 'Determine what the  
47 water is used for, this determines quality criteria; Test the water; Compare with  
48 criteria'. (The final poster looks as given in Figure 2)

¶ As expected, the basic procedural steps a to c (Table 2) could easily be triggered amongst students in

**Deleted:** : the water samples need to be measured (second step) and compared with something (third step), depending on the water use (first step)

[Insert Figure 2 about here]

**Deleted:** The teacher wrote the students' answers on the 'procedure poster' according to plan (see section 'The episodic storyline of the unit').

Based on the group answers and how these were reflected in the class discussion, we concluded that the answer to question 1B is 'Yes'.

*1C: Did students realise that they needed additional information to be able to take the next step of the procedure?*

**Deleted:** ¶ That students saw the need to *compare* their test results with what they considered to be an appropriate standard was further confirmed by how they discussed the case of drinking-water in a class discussion in episode 2. In this discussion several students suggested to compare the sample with 'good water' or 'tap water'. ¶ Based on the group answers and how these were reflected in the class discussion, we concluded that the answer to question 1B is 'Yes'. ¶

Each of the eight groups was given a water sample. Students were asked to discuss in their group whether they thought they could assess the water quality, and if not what additional information they felt they needed.

**Deleted:** of the case of monitoring water quality in episode 2

Group answers

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The groups came up with all kinds of general ideas about what might be measured ('pH', 'bacteria', 'things in there') and strategies (e.g. compare with tap water under the microscope). The question what exactly should be measured (which parameters) and how this could be done, was not raised explicitly in the small group discussions.

Class discussion

There is evidence, however, that students did realise that they needed to find out which substances should be measured and what to compare their test results to (see below, question 2). Therefore we concluded that the answer to question 1C is 'Yes, but not made explicit'.

**Deleted:** The evaluative discussion about which step to add to the poster also showed that the need to find out from the professional practice what exactly should be measured (which parameters) and how this could be done, was not raised explicitly in the small group discussions.

After the evaluative class discussions the teacher added to 'procedure poster' (see Figure 2) the following step: 'Find out what and how much the water contains'

**Deleted:** After the evaluative class discussions the 'procedure poster' looked

**Deleted:** as shown in Figure

Question 2: When carrying out their plan, did students become aware of their knowledge gaps and did this raise the need to consult the professional practice?

Deleted: [Insert Figure 3 about here] ¶

This question is divided into sub-questions 2A and 2B.

Deleted: (Episodes 2-4)¶

2A: Did the step 'test the water samples' trigger the need to consult the professional practice for the necessary information?

Deleted: (what to test and how)

In most groups students themselves (without being asked first) looked up in their course manual what substances they should test for and how they should test these things in a description of the professional practice. Two groups had not yet found that description, but after being directed to it immediately made use of it. Based on this we concluded that the answer to question 2A is 'Yes'.

Deleted: The groups were asked to proceed with the next step of their plan (test the water). In most groups consensus was easily reached about what step

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Deleted: e information and asked where to find it thus explicitly expressing the need for information about what to test.

2B: Did the step 'compare' trigger the need to consult the professional practice for the necessary information?

The students performed the tests and all the groups automatically and naturally compared their test results with the norms that they, again, looked up the description of the practice in their course manual. All groups immediately concluded that the water quality was 'not good', because 'the acidity result clearly exceeds the norm' (typical answer, uttered in the group discussions and written down, without interference or help from the teacher). This conclusion was put forward and generally subscribed to in the class discussion.

Deleted: After all the groups found out that in the professional practice drinking-water quality is monitored for chloride, nitrite, acidity and E-coli, t

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Deleted: Some groups found this information by themselves, some asked where they could find it, thus explicitly expressing the need for finding an appropriate standard.

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That students experienced the functionality of the tests beforehand, and therefore as meaningful, also emerged from the post-interviews. When discussing the tests, students typically referred to experiences such as 'you know all the time why you are doing things' and 'we were doing real tests, with a purpose'.

Deleted: when discussing the tests:

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¶ You know all the time why you do things, like the tests. ¶  
Yes, like the tests we are doing now [the student referred to some tests they just . . . did in the regular chemistry lesson]. I don't know what we are doing. Ok, I do . . . it, but for what? What does it mean?

Based on this we concluded that the answer to question 2B is 'Yes'.

**Deleted:** We were doing real tests, with a purpose.¶

*Question 3: Were the new steps, resolving uncertainties with respect to the limited list of parameters and with respect to the test results, functional to students?*

This question is further split into sub-questions 3A, 3B and 3C.

**Deleted:** (Episodes 4-6)¶

*3A: Did students explicate the expected uncertainties?*

We expected students to be uncertain about their test results and about the limited list of measured parameters. This was indeed the case when they were doing the tests. We expected that these uncertainties would be expressed by the students when trying to draw a conclusion about the drinking-water quality based on their test results. This did not happen. As the acidity test results clearly exceeded the norms, the experienced uncertainties were no longer relevant. All groups concluded without reservations that the water quality was not good. It took an additional intervention by the teacher (see question 3B) to make students express their uncertainties in the context of drawing a conclusion about water quality.

**Deleted:** were expected

**Deleted:** (in the process of doing the tests)

**Deleted:** According to the design, these uncertainties were to be used for functionally introducing the topics of 'argumentation for selecting parameters' (episode 5 'do we trust the limited list of parameters?') and 'accuracy and reliability' (episode 6 'do we trust the test results?').

**Deleted:** in their groups

Based on this we concluded that the answer to question 3A is 'Yes, but later than intended'.

**Deleted:** For reasons to be explained below (3B), this did not happen. That is, the students did articulate the expected uncertainties in the small group discussions when doing the tests, but not when trying to draw a conclusion based on their test results. In the answer to question 3B, we indicate how and when students did articulate the expected uncertainties.

*3B: Did students feel the need to resolve these uncertainties in order to be able to solve the sample case?*

As the acidity test results clearly exceeded the norm, all groups were convinced that the water quality was not good and that they had solved the case.

In order to nevertheless evoke the need to resolve their uncertainties, the teacher put forward the question 'suppose all four parameters were within the norm, would you

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drink this water?’ in the evaluative class discussion. Almost all the students agreed they would not, putting forward some uncertainties about the test results and also uncertainties about the limited list of measured parameters. The teacher collected and classified these uncertainties on the blackboard (Table 4).

[Insert Table 4 about here]

After the evaluative class discussion, the following steps to the ‘procedure poster’ were added (see Figure 2): Find out if we can trust the test results (Did we perform ok?; Are the results accurate enough?); Find out if we can trust the limited list of parameters (Why these four?; Shouldn’t we test for more things?); Assess

Based on our findings we concluded that the answer to question 3B is ‘No, a new purpose needed to be introduced’.

3C: *Did students resolve their uncertainties?*

1) Uncertainties with respect to the limited list of parameters

In this episode the groups were presented with the complete, much longer list of drinking-water parameters and norms. In their groups they addressed their uncertainties by finding out why the four parameters are on this list, why these four are measured and why not others, for example the very poisonous mercury. The students were given information sheets from the professional practice in their groups.

Group answers

Three groups came up with typical answers such as: ‘The value [of pH] changes when something poisonous is in the water, something might be wrong’ and ‘nitrite is an indicator for organic waste’. One group came up with the complete answer for chloride

**Deleted:** After the evaluative class discussion, the ‘procedure poster’ looked as shown in Figure 2

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[Insert Figure 4 about here] ¶  
¶

**Deleted:** In retrospect we concluded that the question ‘is the water quality good enough for the water use’ is not a suitable leading question. It does not provide for a reason to check *all* four parameters whatever the test results are, and draw conclusions for *all* four parameters (which would include solving uncertainties). For, if the acidity test results exceed the norm, why measure chloride? In the professional practice, all four parameters are always monitored and the accuracy of the method is always reviewed, because if something is wrong it will for example provide relevant information about a probable cause for this deviation. The professional practice primarily addresses a different question: what is the water quality in view of the water use? ¶

**Deleted:** After discussing in the evaluative class discussion why the four parameters are on this list, why these four are tested and why not others, students accepted that the four parameters are adequate indicators for drinking-water quality. When something is wrong it will show in the values of these four (see for example protocol A line 4 and protocol B lines 4, 9, 14-17). This conclusion was supported by the analysis of the answers

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'when chloride exceeds the norm it is a sign that something went wrong in the production process'. Two of the groups mentioned 'chloride' only as a general indicator.

#### Class discussion

Protocols A and B are excerpts from the evaluative class discussion They indicate that students accepted that the four parameters are adequate indicators for drinking-water quality. When something is wrong it will show in the values of these four (see for example protocol A line 4 and protocol B lines 4, 9, 14-17).

#### Protocol A

1. T: How is it possible that mercury is forbidden, but not on the list [*of standard parameters to be measured*]?
2. S-1: Mercury just does not occur naturally in nature. It must be dumped or something.
3. T: Sure, but ok, it might be dumped.
4. S-2: The test results will probably differ if there is mercury in the water.

#### Protocol B

T [*Reads aloud*]:

1. Can we trust the list of quality criteria?
2. Why does the laboratory monitor the water only for E-coli, bacteria, chloride, acidity and nitrite routinely?
3. S-2: Because those are the most important.
4. S-3: When the water contains certain substances, the pH will change.
5. T: Yes, very good.

**Deleted:** Protocol A lines 2–4 of the evaluative class discussion shows that some students suggested that the other parameters on the list (other than the four that are monitored) are not probable. Additionally, the teacher, not the students, put forward that it would take too much time and would be too expensive to monitor all these parameters. The students immediately saw the logic of this however, as evidenced by their observed approving utterances. ¶



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6. You can say, and I heard S-2 and previously S-1 mention this, that these four give an indication of the water quality.
7. If one of these four is not good, then they will look further.
8. *[Reads aloud]* Can you think of a situation in which the laboratory will monitor extra parameters? Well, that should be easy to answer.
9. S-4: If one of those four is not right.
10. T: Exactly
11. *[Reads aloud]* You measured the four parameters yourself; do you consider that to be good enough? Who has an opinion about that?
12. S-5 I think it is ok.
13. T: You think it is ok, S-5, why?
14. S-5: Well if there is something else in the water, then the others *[refers to the four parameters]* will change. So then you will know that something is wrong.
15. S-6: Actually I do not trust it, because the pH is too low everywhere *[refers to the test results]*.
16. So we should see if there is something in the water.
17. S-7: *[a bit impatient to S-6]* Well, that is exactly what they do.

## 2) Uncertainties with respect to the test results

The students were asked to discuss in their groups suggestions to evaluate the reliability of their performance.

Typical suggestions were:

Use a known solution to test the test.

Deleted: (Episode 6)¶

1  
2 Use a new Merck-kit phosphate test and compare.  
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6 Due to time limitations, the suggested experiments were not carried out. As a result  
7 these particular uncertainties were only partly resolved.  
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10  
11 With respect to the accuracy of the test results, students discussed the chloride, nitrite,  
12 acidity and E-coli tests in successive group activities. In the subsequent evaluative class  
13 discussions about the different tests, the students agreed that none of the tests were very  
14 accurate in view of the spread in test results, but accurate enough for this case. Despite  
15 the spread, in all cases the test results (accept for acidity) were well within the norm.  
16  
17 After evaluating the accuracy of the test results, the students agreed with the teacher  
18 that 'Estimate spread and position' of the test results should be added to the 'procedure  
19 poster' (Figure 2).  
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30 The post-interviews provide for additional evidence that students felt their uncertainties  
31 were really addressed. Students typically refer to episodes 5 and 6 as follows.  
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36 It [*refers to the uncertainties*] was all written down and then we really got into it.  
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40 Based on this, we can conclude that episodes 5 and 6 were generally functional for  
41 students in the sense that they addressed and resolved most of their uncertainties. The  
42 answer to question 3C is therefore 'Yes, except with respect to their performance of the  
43 tests'.  
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Deleted: [Insert Figure 5 about here] ¶

Deleted: However, both episodes were more complex than the other episodes, each consisting of a series of activities. And not all of these activities turned out to be functional within the respective episode. ¶

Question 4: Did students consider reflecting on what they had learned, with regard to what they had wanted to achieve, to be a functional activity?

This question is answered by means of two sub-questions, 4A and B.

4A: Did students consider writing a report to be a functional activity?

After episode 4 all groups filled out a final report on their findings and conclusions with respect to the exemplary case of drinking-water. All groups were able to fill out the report and expressed their assessment adequately and without help from the teacher. In post-interviews students said they considered this to be the logical conclusive activity of the case. Based on this we conclude that students experienced writing a report as a functional activity and that the answer to question 4A is 'Yes'.

Deleted: (Episode 7)¶

Deleted: In post-interviews students said they considered this to be the logical conclusive activity of the case.

4B: Did students consider designing a manual for a fellow student for another case to be a functional activity?

In this episode students looked back at their initial purpose: what do we know about how people monitor water quality, after having simulated the case of monitoring drinking-water quality? Students were to experience the functionality of checking these intuitions by designing a manual for a fellow student for another case.

Students made a distracted impression and asked a lot of 'what to do' questions. The problem was not so much of a conceptual nature. For when they finally put their mind to it all groups produced an adequate manual. The problem was rather that students had lost a sense of purpose. In response to the questionnaire, when asked about the logic and usefulness of the activities in the unit (in general), four students specifically mentioned the main activity of episode 8 as 'not relevant', 'this should be skipped'.

Deleted: (Episode 8)¶

Deleted: As explained earlier, we expected that students by now would intuitively know that the procedure for monitoring water quality is generally applicable, although the specific details may be different for each case (the parameters, norms, test methods, etc.). We expected that s

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Deleted: had difficulty with understanding what exactly was expected of them. They

Deleted: and most groups made a 'slow start'

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Based on these findings we conclude that students did not experience this episode as functionally embedded. The answer to question 4B is therefore: ‘No, but they all completed the assignment adequately’.

**Deleted:** In retrospect, writing a manual for a fellow student for another case is not part of the practice of monitoring water quality, it is an entirely different practice. ¶

## Discussion

Based on our findings we conclude that the research question can be answered positively and that we delivered a proof of principle. It is possible to provide students with a sense of purpose by establishing functional means-end relationships in an instructional version of a practice. A summary of our findings is presented in Table 5.

**[Insert Table 5 about here]**

Questions 1A and 1B show that the expected advance organizer was explicated by students, and that it largely functioned as an anchor for functional activities (2A and B). Additionally, as expected the results showed that students did raise uncertainties about the limited list of monitored parameters and about the test results (3A). However, the leading question of the exemplary case, ‘Is the water clean enough for its purpose?’, was not suitable for inducing the need to resolve these uncertainties. Students knew that acidity exceeded the norm, which sufficed to answer the question. The teacher managed to redirect the students’ attention at the uncertainties by asking them ‘Suppose all four parameters were within the norm, would you drink the water?’ (3B). In this somewhat forced way, episodes 5 and 6 regained their functionality for students (3A-C). In order to achieve this in a more natural way we now believe that the leading question should have been different, namely analogous to the professional practice: what is the water quality? This calls for a slight redesign of the earlier episodes. A more serious redesign

1  
2 is required for episode 8. Although students were able to successfully complete the  
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4 assignment of episode 8, they did not consider this a functional activity (4B). This  
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6 episode asks for an orientation on a different kind of practice.  
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## 10 Conclusions

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12 Our goal was to explore whether it is possible to provide students with a sense of  
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14 purpose in a prototypical instructional version of a professional practice. We think to  
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16 have achieved our goal for the case discussed in this article. We will now touch upon  
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18 issues that concern the broader applicability of our approach.  
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Deleted: by balancing the student perspective with that of the teacher/course designer

Deleted: Students were to have a sense of purpose, in the sense that they knew what an activity was going to contribute to their objective. The teacher/course designer was to facilitate this and to ensure that the targets were achieved.

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21 First of all, it may be asked if the success we claim is not due to the fact that the  
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23 chemistry involved was not very difficult and that we did not, for example, develop  
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25 chemical concepts such as pH or ionisation, or went into the chemistry behind the tests  
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27 involved. In part our choice has to do with the age of the students and the pressure of  
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29 their school's time table. But there is also a more fundamental reason which has to do  
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31 with our aim of enabling students to perceive their learning as functional for obtaining  
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33 their objectives. If students want to find out how water quality is monitored, and want  
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35 to achieve this by simulating the professional practice, they naturally hit upon, e.g., the  
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37 question why it is that only four parameters are routinely monitored. Given their aims,  
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39 it suffices to understand why the four parameters jointly are sufficient indicators in the  
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41 following terms: acidity is easily influenced by the presence of pollutants; high levels  
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43 of chloride indicate that something may have gone wrong with the production of water,  
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45 etc. Learning about the chemistry of the processes involved is not functional for the  
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47 students' purpose and would rather distract them from their aim. In our opinion it is a  
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49 common mistake of context-based projects to loose sight of the functionality of the  
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51 scientific knowledge taught for the context at hand. Nevertheless it is a valid question  
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if our approach can also be used or adapted to make students acquire more profound scientific knowledge in a for them functional manner. Studies are under way that address this question, e.g. concerning the topics of mechanics and dynamic ecosystems (Author, 2008; Westra, 2008).

We now turn to a second, partly related, issue concerning the broader applicability of our approach. In order to not loose sight of the functionality of the content to be taught, we consistently make a distinction between student functions (of an activity or an episode) and teacher functions.

Paying explicit attention to the student perspective elucidates how the professional practice differs from its instructional version and why it does. Professionals typically do not write down their insecurities while carrying out tests, or ask themselves why they test water on only four specific parameters. Nevertheless, these activities were included in the instructional version for good reasons. Conversely, students are not required to deliver an authoritative report on the quality of a particular water type. We feel that this touches upon a more fundamental discussion as it is becoming increasingly popular to use so-called authentic, or professional, practices or problems as a context to involve students in learning science (e.g., Edelson, 1998; Gläser-Zikuda, Fuß, Laukenmann, Metz, Randler, 2005; Rivet et al., 2000; Roth, 2003; Schwartz & Crawford, 2004). In our opinion the use of authentic contexts or problems does not automatically increase student involvement. Initially, of course, students may be thrilled and strongly motivated to become involved in 'something real'. However, we think that it generally cannot be the case that students are able to conceptualize the goals and direction to follow with the same width and depth as the professionals of that practice. Therefore, as this design research showed, the course designer will have to purposefully deviate from the authentic practice in order to secure that the learning activities remain purposeful

**Deleted:** We will now touch on issues connected to the question what makes it possible. First of all, the professional practice we used follows a procedure that closely resembles the experiences and knowledge of 14-15 year old academically streamed students. This type of practice seems particularly useful for identifying suitable advance organizers to base instructional versions on. However, this study was just a first exploration of the idea and in order to be able to draw more profound conclusions about its usefulness, further research is necessary (cf. Prins, Bulte, Van Driel, & Pilot, 2008)¶  
Furthermore, to ensure that both perspectives, that of students and that of the teacher/course designer, were paid adequate attention, we had to consistently make a distinction between student functions (of an activity or an episode) and teacher functions. For students, to formulate a plan was a functional activity because they were motivated to simulate the practice. For the teacher, to provide students with interesting cases was a functional activity because it motivated the students and at the same time helped activate their rudimentary knowledge to be used as an advance organiser.

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(and in this sense authentic) for students. The challenge therefore is to build on the initial motivation, and to extend it in such a way that it directs the teaching-learning process, balancing the student perspective with that of the course designer *all the way*.

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**Deleted:** A similar remark can be made regarding another strategy that is seen as promising for involving students in learning science: giving them autonomy of choice to a certain extent (Osborne, 2003; Roth, 2003). The assumption is that autonomy of choice will increase ownership of the students over their learning process, and that this will motivate them (Enhag & Niedderer, 2007). However, when given full autonomy of choice, it becomes doubtful whether the students will learn what the course designer intends them to learn. It would ask of students, so to say, that they are able to design their own individual meaningful learning process. Especially in the case of such complex subjects as chemistry or physics this is probably too much to ask of them. Edelson (1998) points out, for example, that before students are able to formulate a question that does count as scientific (according to the course designer), and before they are able to address such a question in a scientific way, students are first to accumulate knowledge and master tools and techniques. Therefore, if students were given full autonomy with respect to formulating and answering their own questions, they probably would not arrive at the targets set by the course designer. Let us give one other example. Roth (2003) let students decide themselves which questions they wanted to address, planning their own activities when participating in a practice of environmentalists. This initial autonomy of choice, however, leads to a decrease of ownership in later stages of students' learning process, when environmentalists, teachers and parents provided students with guidance and information that the students had not asked for. ¶ These examples show that also in giving students autonomy of choice, somehow an optimal balance should be struck between the student perspective and that of the course designer. As compared to the approach of Roth, in the initial stages of our unit on water quality students clearly are less autonomous in the choices they are allowed to make. Nevertheless, in post-interviews many students indicated that what they had especially appreciated about our unit was the attention for their input and that they themselves had been allowed to determine the course of the process to quite some extent. ¶

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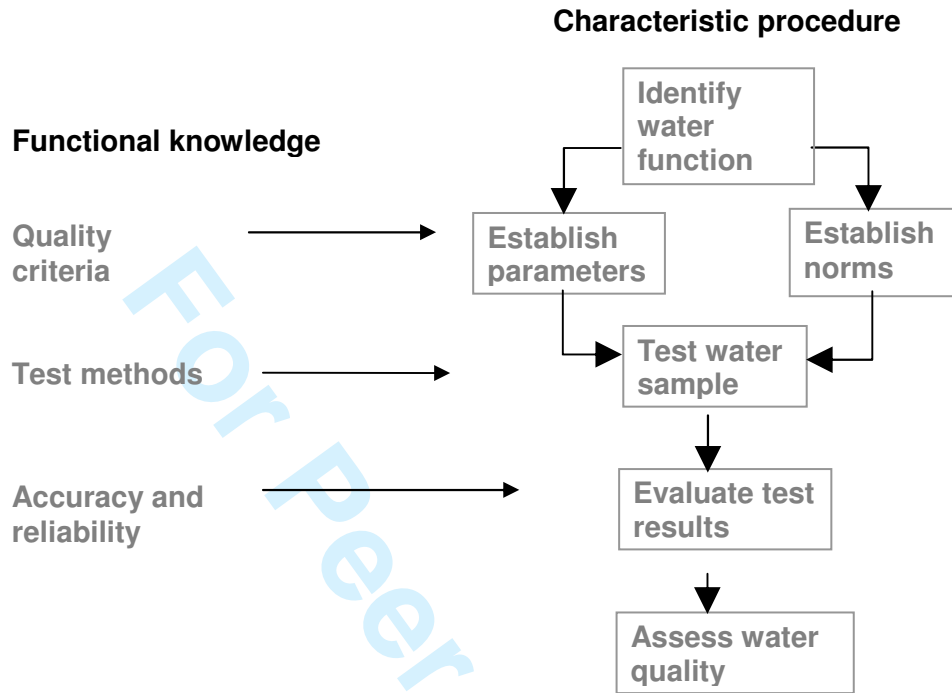


Figure 1: The procedure for monitoring water quality

|  |   |
|--|---|
| Determine what the water is used for, this determines quality criteria |   |
| Test the water   | Find out what and how much the water contains   |
| Compare with criteria  | Find out if we can trust the test results<br>i Did we perform ok?<br>ii Are the results accurate enough?<br>Determine spread and position of the test results |
| Assess   | Find out if we can trust the limited list of parameters<br>i Why these four?<br>ii Shouldn't we test for more things?   |

Figure 2: The procedure poster after episode 6

Table 1: Overview of the practices

| Case                              | Question   |
|-----------------------------------|--|
| Aquarium water from a zoo         | Is it safe for the sensitive rainbow fish?           |
| Swimming pool water               | Is it safe for swimming?                             |
| Drinking-water                    | Is it safe to drink?                                 |
| Brewing water for beer            | Is it sufficiently safe and tasty to brew beer with? |
| Purified sewage water             | Can we safely discharge the water into the river?    |
| Surface water in a nature reserve | Is it clean enough for the diverse water life?       |
| Sea water for swimming            | Is it safe for swimming?                             |

Table 2: The episodic storyline of the unit

|   | Student functions   | Teacher/designer functions   |
|---|---|--|
| <b>Context setting part</b><br>( <i>Episode 1</i> ) | Find out why and how we are going to study the practice of monitoring water quality.  | <p><i>Why</i><br/>Motivate students to find out how water quality is monitored, by connecting this purpose to a variety of societal values and personal interests (health, safety, clean environment etc.).</p> <p><i>How</i><br/>Draw out procedural and conceptual rudimentary knowledge, to serve as an advance organizer, by making explicit the following steps as both directive and still defective concerning the details.</p> <ol style="list-style-type: none"> <li>Determine the function of the water; this determines the quality criteria</li> <li>Monitor the water sample: does the water quality meet the criteria?</li> <li>Compare the test results with an appropriate standard.</li> </ol>  |
| <b>Middle part</b><br>( <i>Episodes 2 to 7</i> )    | In order to find out how people monitor water quality we are going to simulate the practice for the exemplary case of drinking-water, carrying out our plan and collecting information from the professional practice where needed. | <p><i>Guide students in carrying out the above plan</i></p> <ol style="list-style-type: none"> <li>Take step a, by focussing on a sample case of drinking-water that should be healthy and safe</li> <li>Take step b, by having students consult the professional practice concerning the parameters that are routinely monitored for the case of drinking-water (chloride, E-coli, nitrite and pH) and by having them learn about ways to test these four parameters. In the process ask students to write down any uncertainties they have about the test results and the way they perform their tests.</li> <li>Take step c, by having students consult the regulated list that contains the norms for the relevant parameters, but also other parameters and norms that apply to drinking-water.</li> </ol> <p><i>Guide students in refining the plan where appropriate</i><br/>In the above process, doubts and uncertainties are expected to come forward. In the context of making a final assessment of the water sample, these doubts and uncertainties are made explicit in the questions 'why are only these four parameters monitored?' (introducing episode 5) and 'are the test results sufficiently accurate and reliable?' (introducing episode 6).</p> <ol style="list-style-type: none"> <li>Discuss the selection of parameters in the context of making a final assessment.</li> <li>Discuss the concepts of accuracy and reliability in the context of making a final assessment.</li> <li>Write a report.</li> </ol> |
| <b>Evaluation part</b><br>( <i>Episode 8</i> )      | In order to find out if we have learned enough about the way water quality is monitored, we determine whether what we have learned is applicable in another case.   | <p>Guide students in making explicit a general procedure for monitoring water quality.</p> <p>Make connections to other practices, as a preparation for later units. E.g. the <i>production</i> of water of drinking-water quality, or the monitoring of the quality of <i>other products</i>.</p>   |

Table 3: Overview of the evaluation (sub-)questions

*Is it possible to provide students with a sense of purpose by establishing functional means-end relationships in an instructional version of a professional practice?*

| Episode | Question  | Sub-question  |
|---------|---|---|
| 1       | Q 1: Did students explicate the expected advance organizer in the context-setting episode of the instructional version of the practice?                       | Q 1A: Did students value the purpose of the instructional version of the practice?<br>Q 1B: Did the students explicate the procedural steps and their knowledge needs as expected?<br>Q 1C: Did students realise that they needed additional information to be able to take the next step of the procedure? |
| 2-4     | Q 2: When carrying out their plan, did students become aware of their knowledge gaps and did this raise the need to consult the professional practice?        | Q2A: Did the step 'test the water samples' trigger the need to consult the professional practice for the necessary information?<br>Q2B: Did the step 'compare' trigger the need consult the professional practice for the necessary information?  |
| 3-4     | Q 3: Were the new steps, resolving uncertainties with respect to the limited list of parameters and with respect to the test results, functional to students? | Q 3A: Did students explicate the expected uncertainties?<br>Q 3B: Did students feel the need to resolve these uncertainties in order to be able to solve the sample case?<br>Q 3C: Did students resolve their uncertainties?  |
| 5-6     |   | With respect to the limited list of parameters (5) and with respect to the test results (6)?  |
| 7-8     | Q 4: Did students consider reflecting on what they had learned, with regard to what they had wanted to achieve, to be a functional activity?                  | Q 4A: Did students consider writing a report to be a functional activity?<br>Q 4B: Did students consider designing a manual for a fellow student for another case to be a functional activity?  |

Table 4: Uncertainties raised by the students in episode 4

| <b><i>Do we trust the test results?</i></b>                    | <b><i>Do we trust the limited list of parameters?</i></b>        |
|--|--|
| Chloride test: precipitation?                                  | Why these four?  |
| The acidity test results are not the same.                     | Should we not monitor the water for something else, more things? |
| Estimation mistakes when comparing colours.                    |  |
| Pouring the water through the filter: is all the chloride out? |  |
| Did we fold the filter correctly [ <i>chloride test</i> ]?     |  |
| Nitrite test tube shows no colour.                             |  |



Table 5: Overview of the evaluation questions and findings

*Is it possible to provide students with a sense of purpose by establishing functional means-end relationships in an instructional version of a professional practice?*

| Episode | Question  | Sub-question  | Findings   |
|---------|---|---|--|
| 1       | Q 1: Did students explicate the expected advance organizer in the context-setting episode of the instructional version of the practice?                       | Q 1A: Did students value the purpose of the instructional version of the practice?  | Yes  |
|         |   | Q 1B: Did students explicate the procedural steps and their knowledge needs as expected?  | Yes  |
|         |   | Q 1C: Did students realise that they needed additional information to be able to take the next step of the procedure?                               | Yes, but not made explicit.  |
| 2-4     | Q 2: When carrying out their plan, did students become aware of their knowledge gaps and did this raise the need to consult the professional practice?        | Q2A: Did the step 'test the water samples' trigger the need to consult the professional practice for the necessary information?                     | Yes  |
|         |   | Q2B: Did the step 'compare' trigger the need to consult the professional practice for the necessary information?                                    | Yes  |
| 3-4     | Q 3: Were the new steps, resolving uncertainties with respect to the limited list of parameters and with respect to the test results, functional to students? | Q 3A: Did students explicate the expected uncertainties?  | Yes, but later than intended.  |
|         |   | Q 3B: Did students feel the need to resolve these uncertainties in order to be able to solve the sample case?                                       | No, a new purpose needed to be introduced.                                     |
| 5-6     |   | Q 3C: Did students resolve their uncertainties?<br><br>With respect to the limited list of parameters (5) and with respect to the test results (6)? | Yes, except with respect to their performance of the tests (part of episode 6) |
| 7-8     | Q 4: Did students consider reflecting on what they had learned, with regard to what they had wanted to achieve to be a functional activity?                   | Q 4A: Did students consider writing a report to be a functional activity?   | Yes  |
|         |   | Q 4B: Did students consider designing a manual for a fellow student for another case to be a functional activity?                                   | No, but they all completed the assignment adequately.                          |