

# Context-based science curricula: Exploring the didactical friction between context and science content

J. Kortland – Freudenthal Institute for Science and Mathematics Education, Utrecht University, the Netherlands

## Abstract

Context-based science curricula under construction since the 1970s appear to display some didactical frictions when analysed retrospectively from the point of view of a problem-posing approach to teaching-learning. The core of such an approach is that students are provided with a motive for extending their science knowledge, skills and attitudes in a certain direction and therefore continuously are aware of why they are learning what. In view of such an approach, the didactical frictions in context-based teaching-learning materials relate to a weak or lacking real motive for learning and a mismatch between the supposed motive and the science content to be learned. These didactical frictions might be solved by giving the concept of context the more strict meaning of an 'authentic practice' in which typical problems provide a relatively self-evident motive for starting to go through a characteristic procedure for solving these typical problems which requires an input of relevant science knowledge, skills and attitudes.

This paper attempts to explore the didactical frictions in context-based curricula and to tentatively answer the question whether the idea of restraining contexts to authentic practices could be helpful in solving these.

## Background, aims and framework

In context-based science curricula – such as *ChemCom*, *PLON*, *Salter's Science*, *Chemie im Kontext* and *Physik im Kontext* – practical applications and/or socioscientific issues act as a starter for the teaching-learning of science in an attempt to bridge the gap between the often abstract and difficult science concepts and the world the students live in. It was and still is expected that relating science to everyday life would make science teaching more interesting for a larger proportion of the students, that they would be more motivated to learn about, and thus would reach a better understanding of, the subject knowledge involved – although some of the projects mentioned would be glad to reach the first point only. This implies that the science content presented is necessary, and thus its learning is meaningful, for solving a practical or theoretical problem set by the context. In our experience, however, this relation between context and science content is not quite as unproblematic as it seems. From the point of view of designing teaching-learning sequences the problem appears to be a twofold didactical friction between context and science content: is science content really necessary for solving the practical or theoretical problem set by the context, and, if so, which science content?

This paper attempts to explore these didactical frictions by means of a representative example from the PLON curricula – the physics unit *Traffic and Safety* – and to tentatively answer the question whether the idea of restraining contexts to authentic practices – as done in a recently developed chemistry unit *Water Quality* – could be helpful in solving these. The theoretical framework underlying this exploration is the *problem-posing approach* to teaching specific science topics.

### A problem-posing approach

In general, 'traditional' science curricula as well as most context-based curricula adopt a teaching-learning strategy of top-down transmission, without really taking into account what students already know, think and are interested in (Lijnse, 1995). Such teaching almost unavoidably results in a process of forced concept development, which may – at least partly – explain the often disappointing cognitive learning results in science education. This points at the necessity of an improved teaching-learning strategy that takes the students' existing pre-

knowledge and skills into account, and that provides them with a motive to extend these in a specific direction. This reflects the adoption of the perspective of educational constructivism (Ogborn, 1997), combined with the idea of a problem-posing approach with a core of developing content-related motives that drive the students' learning process: a coherent sequence of teaching-learning activities designed on the basis of a profound knowledge of the students' relevant pre-knowledge as being coherent and sensible (instead of being wrong) and using their knowledge productively (instead of immediately trying to change or replace it) in a social process of the teacher's and students' coming to understand each other (Klaassen, 1995; Klaassen & Lijnse, 1996).

An essential element of such a teaching-learning process is to provide students with content-related motives for starting and continuing their learning process. The combination of the students' existing motive for learning and pre-knowledge about a specific topic should be used to induce in them a need for extending their knowledge. In a problem-posing teaching-learning process we aim at bringing the students in such a position that preferably they themselves, guided by the design of the teaching-learning activities, come to formulate this need for extending their knowledge. In other words: preferably the students themselves should pose the problem to be further investigated. As a consequence, throughout the ensuing process of solving the posed problem there should be ample opportunity for the students to put forward their interpretations of what has been learned – interpretations to be taken seriously and used productively by the teacher to drive the teaching-learning process forward. This process is then not only guided by the designed teaching-learning activities (top-down), but also guided by the students' own motives, knowledge and questions (bottom-up).

These ideas about a problem-posing teaching-learning process were introduced and elaborated in a design research project for the topic of radioactivity (Klaassen, 1995), followed by comparable projects about the introduction of an initial particle model (Vollebregt, 1998) and decision making about the waste issue (Kortland, 2001). These studies started the research programme on 'didactical structures' for the teaching-learning of specific topics, and – based on those – more general ones at our institute (Lijnse & Klaassen, 2004). For the purpose of designing teaching-learning sequences these ideas have been worked out into a didactical structure of four subsequent phases with specific didactical functions that have to be fulfilled in such a way that they assure the necessary coherence in the activities of the students:

- Phase 1: Orienting and evoking a global interest in and motive for a study of the topic at hand.
- Phase 2: Narrowing down this global motive to a content-specific need for more knowledge.
- Phase 3: Extending the students' existing knowledge, in view of the global motive and the more specifically formulated knowledge need.
- Phase 4: Applying this knowledge in situations the knowledge was extended for.

To this phase structure other phases can be added, depending on more extended educational aims, e.g. in the area of skill development. The second phase represents one of the main features of a problem-posing approach. Such a phase appears not to be present in the teaching cycles as published in the literature (Abraham, 1998). Those cycles almost exclusively deal with cognitive learning, even though it is also often written that one should not forget about the importance of motivation. In our approach, however, both are taken together and integrated from the start.

## **Results**

In the following two subsections these ideas about a problem-posing approach will be used to

analyse the two teaching-learning sequences mentioned above on their ‘didactical quality’.

### **Learning in contexts**

For taking a close look at the didactical quality of the PLON units in terms of the theoretical framework outlined above it suffices to take the unit *Traffic and Safety* as an example – as all units show roughly the same format (Eijkelhof & Kortland, 1988; Kortland, 2005). The aim of this unit is to have students learn about the relationship between force and motion in the context of traffic-safety measures such as safety belts, crash helmets and speed limits. The related ‘contextual’ aim is to make students aware of, and thus promote, responsible behaviour in everyday life traffic situations through their understanding of the physics involved.

A reconstruction of the didactical structure of this unit along the lines of the theoretical framework shows the following four phases:

- Phase 1: Orienting and evoking a global interest in and motive for a study of traffic safety and measures to enhance this.
- Phase 2: Narrowing down this global motive to those traffic-safety measures that require some physics knowledge about force and motion in order to be able to understand their necessity.
- Phase 3: Extending the students’ physics knowledge about force and motion.
- Phase 4: Applying this knowledge in situations the knowledge was extended for, that is explaining the necessity of traffic-safety measures with the help of the extended physics knowledge about force and motion.

Although – in reconstruction – the unit follows the phase structure outlined in the previous section, there are two serious didactical frictions in the elaboration of these phases.

The first didactical friction occurs in the transition from the first to the second phase. In the first phase the unit states that traffic safety represents a big issue, that numerable measures have been taken to enhance traffic safety, and that those measures have caused a considerable decrease in the number of traffic casualties. Students are asked to infer this from a diagram showing the number of traffic casualties over the years. In the second phase the unit states that the issue will be narrowed down to protecting the drivers of cars and mopeds by legislative measures concerning safety belts, crash helmets and speed limits. The unit further states that for understanding the necessity of such measures some physics knowledge is needed, more specifically related to the way in which these measures reduce the large forces acting on the driver’s body during a collision. The didactical friction here concerns the question whether physics knowledge is indeed needed for understanding the necessity of the traffic-safety measures mentioned – or, maybe more precisely, what is meant by ‘understanding’. Is the kind of understanding of interest to the responsible citizen not simply the fact learned during the first phase that those measures have been quite successful in enhancing traffic safety? Then why would it be important to learn and use physics knowledge to understand the necessity of those safety measures? The unit therefore does not offer the students a content-related motive for an extension of their knowledge about force and motion. This didactical friction could have been dissolved by recognising the fact that the unit actually is about understanding the effectiveness (and not the necessity) of those safety measures.

This first didactical friction, of course, also has its consequences for the transition from the second to the third phase and onwards. However, this transition also reflects another kind of didactical friction. This second didactical friction concerns the kind of knowledge to be extended. If any physics knowledge would be needed for understanding the effectiveness of safety measures, it would be about the forces a human body can endure and the magnitude of forces acting on the human body during a collision without and with a safety measure taken,

including ways to measure and/or calculate these forces. A considerable amount of physics presented in the third phase of the unit clearly does not match with these, for the students logical questions. Students will wonder why they have to know *why* it takes quite some effort to bring a car or moped to a standstill in time and *why* car drivers move ahead during a collision. Why isn't it enough that they know *that* such is the case – something, by the way, that they already know. Furthermore, students will wonder why they have to learn about force and motion in case of constant and increasing speed. The didactical friction, therefore, concerns a mismatch between the unit's main question about understanding the effectiveness of traffic-safety measures and the physics knowledge presented. As a consequence, when analysing the elaboration of the third phase in the unit in the light of the above criticism, about three-quarters of its contents can be considered superfluous.

This criticism of the unit, however, should be softened up a bit. First of all, it is relatively easy to criticise such a unit with hindsight on the basis of growing insight in a desired didactical structure of teaching-learning sequences. Secondly, at the time of writing the unit the main task of its authors was to update and modernise the existing physics curricula – which they certainly did. There is, however, the issue of implementation to consider. For a context-based curriculum to be adopted by teachers, one should probably not move too far away from what generally is regarded as the traditional curriculum content to be taught.

The idea behind a context-based curriculum is to embed science content in a collection of practical situations – such as traffic safety, weather forecasting and energy supply – showing, first of all, that science relates to everyday life and enables us to understand practical applications and socioscientific issues, and, secondly, that science content has a personal and/or social relevance in enabling thoughtful decision making about every day life behaviour. In the unit *Traffic and Safety*, this second aim has led to the suggestion of a *practical orientation*: solving practical problems related to traffic safety issues. In reality, the unit addresses the first aim and asks for developing a *theoretical orientation*, but without an effort of inducing in students the related motive of wanting to understand the effectiveness of traffic safety measures, of giving a preview on the necessary physics knowledge and of establishing a need for extending their knowledge in the light of their pre-knowledge about force and motion. With respect to (re)designing the unit, this will not be easy to elaborate – but, if possible, it would solve the first didactical friction. When the difficult question of *why* physics knowledge is needed in a specific context has been answered, solving the second didactical friction concerning the question of *what* physics knowledge is needed will present less problems. The claim that the acquired physics knowledge has relevance for responsible traffic behaviour, however, must then be withdrawn: for such decision making the introduction of the unit would suffice. What, of course, does not exclude that the acquired physics knowledge could have an corroborative effect, as now students realise how large the forces acting on a body during a collision can be.

From the activity-based teaching-learning in relevant everyday life contexts in the PLON curricula it was expected that students would experience the content taught as more relevant, and that they would be better able to understand and connect the concepts learned to their out-of-school world (Lijnse, 1995). Evaluation research has shown the first assumption to be reasonable. The second, however, has not appeared to be that simple. It appears that the PLON curricula do not differ from 'traditional' curricula as far as the students' cognitive learning outcomes are concerned (Wierstra, 1990; Eijkelhof, 1990). Moreover, it appears difficult to have students use their acquired conceptual science knowledge in practical decision-making situations, especially those situations in which students (might) have already formed an opinion (Eijkelhof, 1990). Research results like these question the relevance of the acquired science knowledge as perceived by the students, and, even further down the line,

question the proper acquisition of that knowledge. These questions seem to reflect the above outlined didactical frictions concerning why science knowledge is needed and, if so, what science knowledge.

### **Learning in the context of authentic practices**

In our experience, other design research projects about teaching-learning sequences with either a practical or a theoretical orientation repeatedly show the same didactical frictions popping up. Given the above mentioned research result that context-based curricula do have a positive impact on the students' perceived relevance, it seems worthwhile to find a way of dissolving these didactical frictions. Turning to contexts as authentic practices might be such a way.

Thinking about contexts as authentic practices implies the attribution of a more strict meaning to the word 'context'. Instead of seeing context as everything or anything in everyday life to which science knowledge can be connected in one way or another, it would refer to communal practices of professionals in science and technology. In general, such an authentic practice can be described as a homogeneous group of people or workers in a 'community of practice', bound together by a common purpose of solving a specific science/technology-related practical problem and by a common type of characteristic procedure leading to a solution of such a problem. The difference with the more broad meaning of the word 'context' probably is the characteristic procedure for solving a practical problem: a procedure in which scientific/technological knowledge, skills and attitudes do come in naturally and therefore unquestioned. With a view to developing the students' motives for extending their knowledge, skills and attitudes in a certain direction as being the core of a problem-posing approach, the question arises whether actively involving students in an appropriate communal practice would dissolve the earlier identified didactical frictions in a context-based curriculum. If so, however, it will be obvious that it is principally and practically impossible to engage students in whatever authentic practice: the people in an authentic practice use their acquired science knowledge, while our students still have to acquire that knowledge. The second question then is how to devise an educational adaptation mimicking such an authentic practice. If this succeeds, such an 'educationalised' authentic practice might help to design a didactical structure in which students see the point and have a motive to extend their knowledge, skills and attitudes in a certain direction at every step in the teaching-learning process, as this extension would be functional for participating in the educationalised authentic practice (Bulte *et al*, 2004). Anyway, for the time being, the idea sounds interesting and promising, not in the least because it seems to be closely related to the four earlier mentioned phases as an expression of a desired didactical structure. However, the existence of a characteristic procedure as the backbone of an educationalised authentic practice requires some additional phases. These additional phases stem from an effort of integrating the teaching-learning of science knowledge with a general procedure for decision making (Kortland, 2001; Lijnse & Klaassen, 2004):

- Phase 5: Creating, in view of the global motive, a need for reflection on the skill involved.
- Phase 6: Developing a (still contextualised) metacognitive tool for an improved performance of this skill.

In these phases, the 'skill involved' reflects the students' ability to work their way through the characteristic procedure. It must be remarked, however, that one condition has to be met for such a teaching-learning process: the intended procedure must be intuitively familiar to the students. Such was indeed the case for the decision-making procedure, but it still remains to be seen for the characteristic procedures in educationalised authentic practices. Before further developing our theoretical framework, an example of how these ideas about using authentic

practices could be elaborated seems appropriate.

As an example will serve a unit in which the educationalised authentic practice was inspired by the authentic practice in which analysts evaluate the quality of water with a certain function (such as drinking it or swimming in it) according to standard test procedures (Westbroek, 2005) as outlined in Figure 1. Characteristic for this practice is that there is an issue (water quality), that there is a procedure (standard protocol for testing) and that there is a problem to be solved (judgement of water quality based upon the findings of the standard protocol for testing). The educationalised version of this authentic practice, of course, differs from its real life setting. In the authentic practice, competent professionals perform the job, knowing why they do what – what standard parameters to test for water with a certain function, which standard tests to perform, how to interpret the results of these tests taking into account their accuracy and reliability against the standard criteria to be met. This, of course, does not hold for students. Whereas professionals recognise the sense of direction for their actions connected to the problem they need to solve, students do not at forehand. In the educationalised authentic practice such a sense of direction has to be provided by using the earlier mentioned phase sequence.

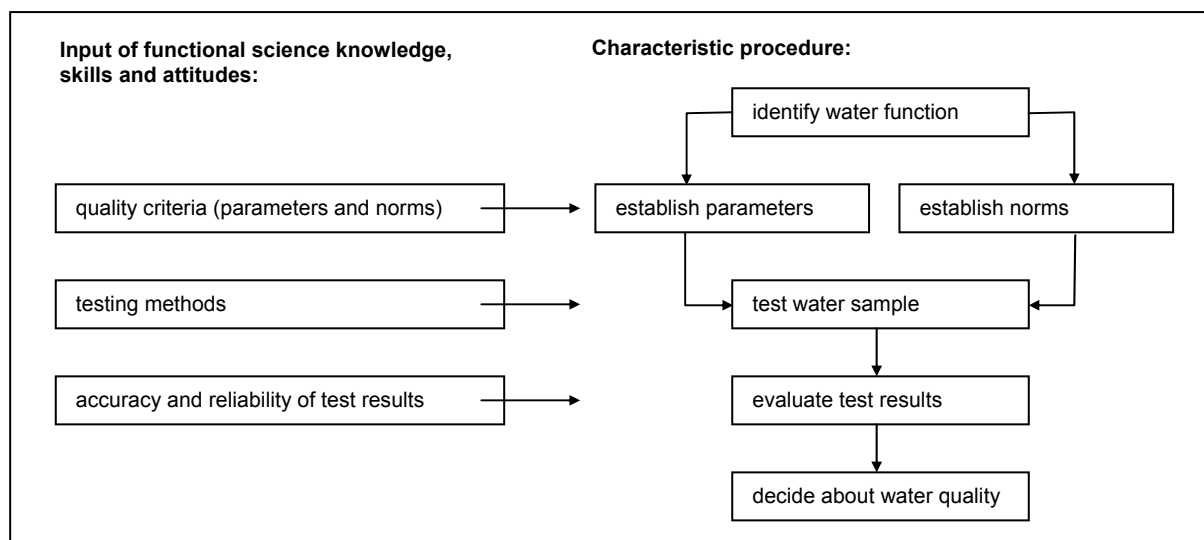


Figure 1 – Characteristic procedure with its input of functional science knowledge, skills and attitudes.

During the first phase students are provided with a broad orientation on the authentic practice by an introduction to several cases that need to be resolved: is this water sample good enough for drinking water, can we use this water for the tropical fishes in the zoo, is it safe to drain this effluent water in the river? By asking the students what they think people have to do in order to get answers to such questions they are provided with a first orientation on the test procedure – and their role in the educationalised authentic practice. They express their common sense notions about the procedure: ‘the water function should be determined because this sets the demands on water quality, the water should be tested to check if it meets the demands, the judgment should be based on the test results.’ Students are expected to be generally interested in getting involved in such a practice.

By focussing on an exemplary problem at the start of the second phase – does this water sample meet the criteria for drinking water? – the students are expected to apply their common sense notions about the issue and about the procedure: ‘We do not know what is in the water, but it should be clear and safe to drink. We should test the water, but need more specific knowledge about precisely what is tested.’ These notions are an expression of the content-related motive for engaging in the next phase.

The third phase is the most extensive learning phase, characterised by cycles of progressive extension of specific issue and procedural knowledge, at some points driven by common sense notions about what will now be the next logical step in the procedure and at other points driven by the evaluative question whether it is now possible to conclude that the water is safe enough to drink. First students extend their issue knowledge in view of their earlier expressed knowledge need: based on four parameters used in the authentic practice, students test the sample on these parameters according to an (adapted) protocol and obtain test results. When asked whether the water meets the demands they realise that their test results should be compared to a reference: the official norms. This information is again derived from the authentic practice. When thereafter asked the same question again, they should realise that they still are not certain yet. They are expected to have their uncertainties about the test results, about the accuracy of the tests and about the rather short list of parameters. These uncertainties represent a new, more specific knowledge need. Thus the students learn about the legal list of drinking water quality demands, which is indeed much longer than the four parameters they tested. They address their uncertainties by answering the questions why the four parameters are on the list and why they are tested, and why those other parameters are on the list and not tested. Next, students need to address their uncertainties about the test results. They should now see the point of learning more about the reliability and accuracy of the test methods. The third phase of knowledge extension is naturally concluded by the fourth phase in which students draw a conclusion about the exemplary case with the help of their extended knowledge.

The expectation is that now, in the fifth phase, after having been successful in solving the exemplary problem, they have a content-related motive for using the procedure for solving the other typical cases of the orientation phase – and thus a motive for first expressing the procedure more explicitly and in more detail. This is done in the final sixth phase where, by subsequently referring to the orientation phase in which other water quality problems feature, students can make the procedure they have used and gradually refined operational for planning how to solve other practice-related problems.

From the evaluation of this unit, there is evidence that students recognised the goals associated with the authentic practice and considered it to be worthwhile to get involved in issues of water quality. In most stages of the teaching-learning process, students did have a sense of direction: based on their evoked common sense notions about the characteristic procedure they knew why they performed a certain activity and had a sufficient idea of the next logical step to take in extending their science knowledge, skills and attitudes. The remaining problem concerns the transition of phases four to five: the students did not really seem to develop a motive for solving the other issues from the orientation phase – a transition which also appeared to be difficult to design in an earlier design research project (Kortland, 2001).

The above described example of the unit about water quality shows that mimicking an existing authentic practice is feasible, without getting entangled in the didactical frictions about the motive for extending their knowledge and the nature of that knowledge as mentioned earlier. There are, however, some conditions to be met for this to hold more generally:

- The authentic practice that serves as a source of inspiration for the mimicked educational version of the practice is such that students appreciate the goals associated with this practice and that they recognise the typical problems as relevant to them and/or to society, thus providing them with a general motive for learning.
- The characteristic procedure of this practice can initially be expressed by students in a rudimentary form in common sense notions, thus providing them with a sense of direction

for their learning.

- The science knowledge, skills and attitudes that are needed to be able to act effectively in this practice are such that students are initially aware of them in broad outlines, though not in the necessary details, thus providing them with content-related motives for their learning.
- The characteristic procedure of this practice should preferably also be recognised by the students as being relevant for other authentic practices, thus providing them with a content-related motive for making explicit the operational procedure.

If these conditions are met, we expect it to be possible to design teaching-learning sequences that continuously make sense to the students, providing them with a motive and a sense of direction for extending their science knowledge, skills and attitudes.

The description of the didactical functions in the phase sequence presented earlier as an expression of the didactical structure can now be somewhat expanded to include the idea of context as educationalised authentic practice. We will do this in general terms, as the aim is to express a didactical structure that could act as a theoretical framework to guide further curriculum development and associated design research. This generalised didactical structure is visualised in Figure 2.

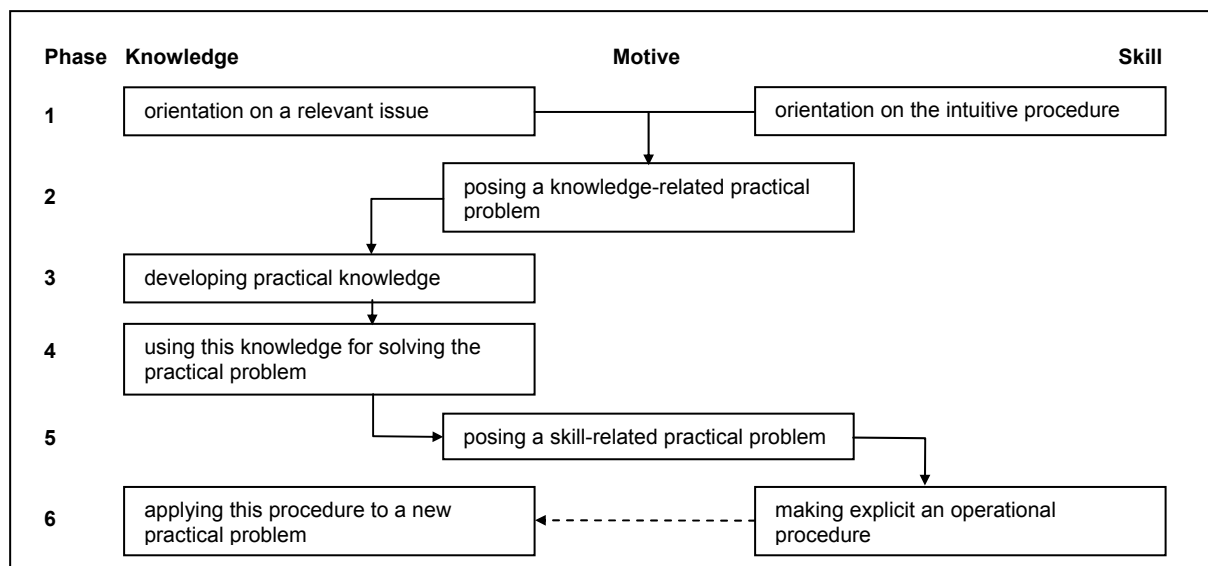


Figure 2 – Generalised didactical structure of teaching-learning sequences inspired by an authentic practice.

- Phase 1: Orienting and evoking a global interest in and motive for a study of the topic at hand – During a broad orientation on the authentic practice, students start to recognise typical problems that are posed in such a practice. They formulate common sense notions about the characteristic procedure of the practice that typically leads to solutions to this problems. Students start to become interested to be involved in an imitation of the practice, when they focus on a specific, exemplary problem because they appreciate the characteristic goals associated with solving such problems.
- Phase 2: Narrowing down this global motive to a content-specific need for more knowledge – Through a first analysis of the exemplary problem, students express and use their pre-knowledge about the science content involved and their intuitive or common sense notions about a characteristic procedure. Students come to realise that, for solving this exemplary problem, their science knowledge is not yet sufficient and therefore has to be extended in a specific direction.
- Phase 3: Extending the students' existing knowledge, in view of the global motive and the more specifically formulated knowledge need – Students proceed through the steps of



their intuitions about the characteristic procedure, whilst extending their science knowledge and, when necessary, also refining steps of the procedure until a satisfactory level is reached.

- Phase 4: Applying this knowledge in situations the knowledge was extended for – Students use their extended science knowledge to solve the exemplary problem, and realise that such knowledge extension has been successful – as expected in the light of their experiences in phase 2.
- Phase 5: Creating, in view of the global motive, a need for reflection on the skill involved – Students come to realise that for solving typical practical problems similar to the exemplary problem, they need to express the necessary steps of the procedure more explicitly.
- Phase 6: Developing a (still contextualised) metacognitive tool for an improved performance of this skill – Students, on the basis of their experiences so far, explicitly express the necessary steps of the complete procedure, and tentatively use this procedure in (planning their) solving other problems typical for the authentic practice or more or less comparable other authentic practices.

## Conclusion

The theoretical framework as presented in the previous section in our own experiences has already shown to be of use when assessing the quality of teaching-learning sequences under construction. And that is one of the things such a framework is for. Gradually this will grow into a more prescriptive character right from the start in developing new teaching-learning sequences. There are, however, still quite a number of uncertainties and questions to be answered. First of all, the notion of authentic practice quite strongly refers to communities of professionals with a vocational connotation. This would probably represent a severe restriction on the choice of contexts in education. However, also scientists can be seen as a community of practice, so that, certainly in the higher years of secondary science education, the work of engineers and scientists in the areas of applied and fundamental research can function as authentic practices. But do such authentic practices reflect a characteristic procedure as a backbone for the educationalised version, or is it more a characteristic way of thinking? And what about life roles other than being a professional worker? What about preparing students for their life roles as a thoughtful consumer and a responsible citizen? Do these two life roles also represent authentic practices? It sounds a bit strained. Could something like ‘acting safely in traffic’, ‘being able to interpret a weather forecast’ or ‘being able to care for household animals’ be considered an authentic practice? And if so, which science knowledge is required as a functional input into which characteristic procedure?

The idea of defining (or restricting) context as an authentic practice with a characteristic procedure requiring a functional input of science knowledge, skills and attitudes so far seems to be a promising and fruitful direction for designing didactical structures that do not display didactical frictions about the motive for extending science knowledge and the nature of that knowledge. It seems to work at the level of separate units – certainly as a source of inspiration for the authors of the teaching-learning sequence when designing its didactical structure. However, whether such an approach is feasible at the level of a complete and coherent context-based science curriculum and whether this would lead to a curriculum with an acceptable science content are still open questions, currently under investigation (Westbroek *et al*, 2007). The guess is that it will be necessary to consider different types of authentic practices, not only vocational ones (such as in the unit about water quality) but also everyday life practices and scientific/technological practices tuned to the age of the students and the ability stream they are in. This would allow the design of curriculum strands, starting off with

(everyday life and/or vocational) authentic practices with a practical orientation, which might be used to evoke curiosity in students about why things are as they are. This then would represent a kind of theoretical orientation giving rise to the choice of also authentic practices in which scientists are engaged in more fundamental research.

## Acknowledgement

The author wishes to thank Kees Klaassen, Piet Lijnse, Astrid Bulte and Hanna Westbroek, my colleagues at the Freudenthal Institute for Science and Mathematics Education, for their valuable input in terms of developing the theoretical framework and exploring the possible role of authentic practices in designing teaching-learning sequences.

## References

- Abraham, M.R. (1998), The learning cycle approach as a strategy for instruction in science. In B.J. Fraser & K.G. Tobin (Eds.), *International handbook of science education* (pp. 513-524). Dordrecht: Kluwer.
- Bulte, A.M.W., H.B. Westbroek, O. de Jong & A. Pilot (2006), A research approach to designing chemistry education using authentic practices as contexts. *International Journal of Science Education*, 28 (9), 1063-1086.
- Eijkelhof, H.M.C (1990), *Radiation and risk in physics education*. Utrecht: CDBeta Press.
- Eijkelhof, H.M.C. & J. Kortland (1988), Broadening the aims of physics education. In P.J. Fensham (Ed.), *Development and dilemmas in science education* (pp. 282-305). London: Falmer Press.
- Klaassen, C.W.J.M. (1995), *A problem-posing approach to teaching the topic of radioactivity*. Utrecht: CDBeta Press.
- Klaassen, C.W.J.M. & P.L. Lijnse (1996), Interpreting students' and teachers' discourse in science classes: an underestimated problem? *Journal of Research in Science Teaching*, 33 (2), 115-134.
- Kortland, J. (2001), *A problem-posing approach to teaching decision making about the waste issue*. Utrecht: CDBeta Press.
- Kortland, J. (2005), Physics in personal, social and scientific contexts – A retrospective view on the Dutch Physics Curriculum Development Project PLON. In P. Nentwig & D. Waddington (Eds.), *Making it relevant. Context based learning of science* (pp. 67-89). Munster: Waxmann.
- Lijnse, P.L. (1995), 'Developmental research' as a way to an empirically based 'didactical structure' of science. *Science Education*, 79 (2), 189-199.
- Lijnse, P.L. & C.W.J.M. Klaassen (2004), Didactical structures as an outcome of research on teaching-learning sequences? *International Journal of Science Education*, 26 (5), 537-554.
- Ogborn, J. (1997), Constructivist metaphors of learning science. *Science & Education*, 6, 121-133.
- Vollebregt, M.J. (1998), *A problem-posing approach to teaching an initial particle model*. Utrecht: CDBeta Press.
- Westbroek, H.B. (2005), *Characteristics of meaningful chemistry education – The case of water quality*. Utrecht: CDBeta Press.
- Westbroek, H.B., A. Bakker, C.W.J.M. Klaassen, K.T. Boersma & A. Pilot (2007), The feasibility of designing a coherent science curriculum inspired by authentic practices. Paper to be presented at the ESERA Conference 2007.
- Wierstra, R.F.A. (1990), *Natuurkundeonderwijs tussen leefwereld en vakstructuur*. Utrecht: CDBeta Press.