

## Scientific Literacy and Context-Based Curricula: Exploring the Didactical Friction between Context and Science Knowledge

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### Abstract

According to the PISA 2000 report *Literacy Skills for the World of Tomorrow*, scientific literacy is 'the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and human interactions with it' (OECD|UNESCO, 2003: p.21). Such a scientific literacy is expected to be the outcome of teaching and learning about socio-scientific issues in science classrooms.

Teaching and learning about socio-scientific issues in science classrooms at present is about forty years old, and maybe even older. It emerged in the 1970s either as stand-alone units meant to be an add-on to the traditional science curricula, or as an element of context-based science curricula under construction at that time. A characteristic of both approaches was to present the science knowledge learned or to be learned as relevant to decision making in personal, social and/or scientific contexts. Over time, however, from these efforts at least two questions emerged: is science knowledge relevant for such decision making (and, if so, which science knowledge), and what can be considered an adequate design of the teaching-learning process?

The intention of this paper is to reflect on some old German and Dutch projects aiming at developing context-based science curricula with a scientific literacy flavour in the 1970s, to identify the pitfalls in terms of didactical friction between context and science knowledge in designing teaching-learning sequences dealing with socio-scientific issues (based on the experiences in those projects, and where possible on the basis of empirical research), and to conclude with some design principles related to the teaching-learning process in such cases.

### Introduction

The PISA 2000 report *Literacy Skills for the World of Tomorrow* (OECD | UNESCO, 2003) defines scientific literacy as "the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and human interactions with it" (p.21). For this, students need "to grasp a number of key concepts in order to understand certain phenomena of the natural world and the changes made to it through human activity", students need to be able "to acquire, interpret and act on evidence", and students are supposed to be able to apply all of this to "issues that have a bearing on life in general as well as matters of direct personal concern". One could say that these are rather ambitious goals, even more so as such scientific literacy is "considered a key outcome of education by age 15 for all students, whether or not they continue to study science thereafter" because "scientific thinking is demanded of citizens, not just scientists".

In classroom practice, since the 1970s (or maybe even earlier), goals like these have been addressed under the label of 'decision making about socio-scientific issues'. Teaching and learning about socio-scientific issues in those days emerged either as stand-alone units meant to be an add-on to the traditional science curricula, or as an element of context-based science curricula under construction at that time. A characteristic of both approaches was to present the science knowledge learned or to be learned as relevant to decision making in personal, social and/or scientific contexts. Examples of such efforts were *Siscon in Schools*, *SATIS* and *Salter's Science* in the UK, the Physics Curriculum Development Project *PLON* in the Netherlands and the *IPN Curriculum Physik* in Germany, of which the latter three could be considered as context-based curricula in which science knowledge was meant to be learned and applied in contexts primarily drawn from 'everyday life'. In terms of 'curriculum emphases' (Roberts, 1982) this approach implied a shift towards an 'everyday coping' and a 'science, technology and decisions' emphasis.

For this paper, I will limit myself to scientific literacy through context-based science curricula, further limited to some illustrative examples of teaching-learning sequences.

As a starter, the first example concerns the socio-scientific issue of energy in transport.

Quite recently we have seen, at least in the Netherlands, a debate about ‘zero emission vehicles’: vehicles powered by electricity instead of diesel or petrol. A debate triggered, of course, by environmental considerations regarding pollution through fossil fuel burning (including the enhanced greenhouse effect and global warming) and, maybe at a somewhat larger timescale, depletion of fossil fuel resources such as coal, oil and natural gas. Illustrative of this debate is the newspaper article in Figure 1 with quotations from Ian Robertson, some boss of the German BMW car company (but not a German, apparently). The discussion is about limited action radius, charging time of batteries and so on, and solutions for those problems. The reason for BMW to invest in electricity-powered cars is the 2012 European emission standard of, on average, 130 g CO<sub>2</sub> for all new sold cars (and 100 g in 2020): “Electric cars emit zero CO<sub>2</sub>. If we are going to sell lots of those, our average will go down.” So, nothing about where all this electricity will come from, and the pollution and depletion of resources related to its production. What is lacking in this newspaper article, and in the debate at large, is a critical reflection on why we might need electric cars, and under which conditions such electric cars might be a solution to which problem.



Figure 1 – A zero emission vehicle (left), and a newspaper article quoting Ian Robertson: ‘Also BMW now believes in small and electric’ (right).

The zero emission vehicle clearly reflects a socio-scientific issue, appearing in newspapers, on television, in programmes of political parties and debates between politicians, in advertisement campaigns of car companies, and so on. An issue with impact “on the natural world and human interactions with it”, so – in the context of scientific literacy as defined above – an issue “to help make decisions about”, both in society at large (by, for example, voting behaviour in elections as an expression of citizenship in a democratic society) and as a matter of “direct personal concern” (by consumer behaviour).

Clearly, BMW boss Ian Robertson, did not get his physics education, if any, in Germany in the 1970s. He might have reacted differently, if he had been taught physics with the *IPN Curriculum Physik*, and more specific the unit *Energie quantitativ: Elektro- oder Benzinauto?* (IPN, 1977). He then would have known that the electricity to power cars comes from burning coal, oil or natural gas, and that the efficiency with which in this case energy is converted ‘from fuel to motion’ is 15% for a traditional car and 16% for an electric car (see Figure 2) – which boils down to hardly any difference as far as fuel consumption and its associated pollution of air and depletion of resources is concerned.

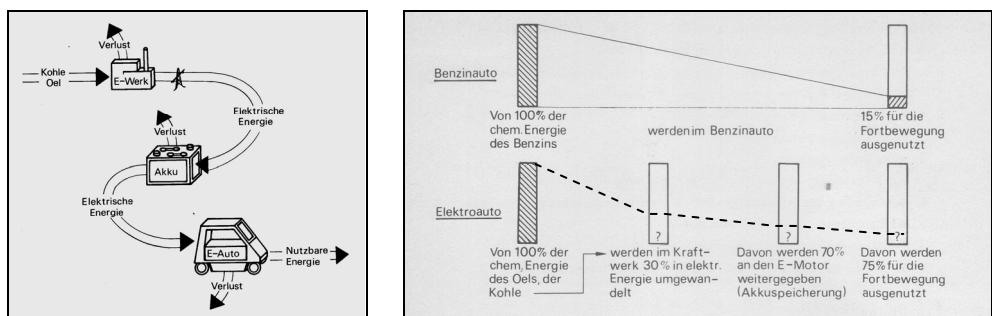
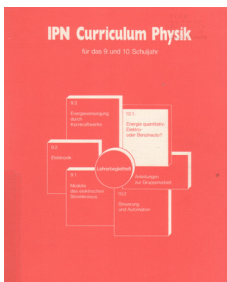


Figure 2 – Two pictures from the IPN unit *Energie quantitativ: Elektro- oder Benzinauto?*: energy transformations in the case of an electric car (left), and the efficiency of those transformations (right). The question marks are to be filled in by the students on the basis of their research projects. The answers to these questions (dotted line) have been inserted by the author.

So, one might say that this now thirty-five years old IPN scientific literacy unit was far ahead of its time in dealing with the concept of energy and energy transformations in the context of electric cars. Since then, of course, technology and data might have changed, but the basic

underlying idea of how to look at energy transformations in the context of such a socio-scientific issue has remained exactly the same.

After this introduction I will take three crude steps through my own history of curriculum development: *learning in contexts*, the *problem-posing approach* and *learning in authentic practices* – each step addressing its claims and specific problems to which the next step was supposed to provide a solution, and thus outlining a search for the *didactical quality* of teaching-learning sequences somehow related to scientific literacy. This search will end with a didactical structure of such a teaching-learning sequence as a design tool, and an overview of pitfalls when elaborating such a didactical structure for a specific socio-scientific issue.

## 1 Learning in contexts

In context-based science curricula – such as *ChemCom*, *PLON*, *Salter's Science*, *Chemie im Kontext* and *Physik im Kontext* – practical applications and/or socio-scientific 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 retrospect, 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 knowledge: is science knowledge really necessary for solving the practical or theoretical problem set by the context, and, if so, which science knowledge?

For taking a close look at the didactical quality of the PLON units it suffices to take the unit *Traffic and Safety* (PLON, 1981) as an example – as all units show roughly the same format as visualised in Figure 3 (Eijkelhof & Kortland, 1988; Kortland, 2005). A unit starts off with an orientation, introducing a basic question taken from the society students live in, and regarded as relevant to the students – at least in the eyes of the project team – with respect to their (future) life roles as a consumer and citizen in society. The second part of a unit addresses basic information and skills: the physics relevant for answering the basic question. This part is followed by a number of options in which groups of students independently do some further work on aspects encountered in the unit's previous part and report their findings to other groups in class. Then the basic question turns up again in the last part of the unit, in which the physics concepts and skills are broadened and/or deepened by applying them to situations in which the basic question is prominent: does the physics taught help in finding answers, help in being able to cope with a technological device, a consumer decision, a socio-scientific issue? This turning back to the basic question – to society – is essential because it reflects the relevance of our physics teaching.

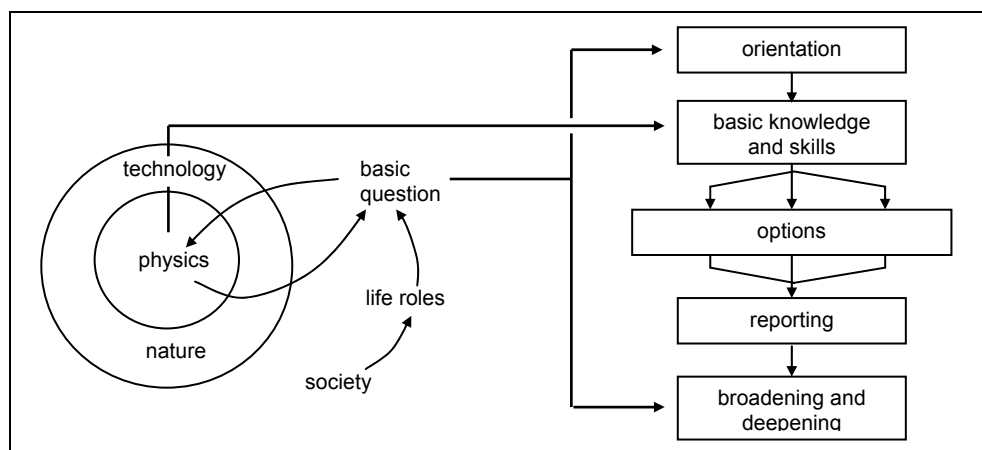


Figure 3 – The format of a PLON unit.

The aim of the unit *Traffic and Safety* 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, thoughtful behaviour in everyday life traffic situations through their understanding of the physics involved.

A retrospective reconstruction of the *didactical structure* (Lijnse, 1995) of this and other PLON units is summarised in Figure 4, in which the four phases each have their specific *didactical function*:

- Phase 1: Orienting and evoking a global interest in and motive for a study of the topic at hand. Or, in other words: inducing a global motive.
- Phase 2: Narrowing down this global motive to a content-specific need for more knowledge. Or, in other words: inducing content-related local motives for knowledge extension.
- 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.

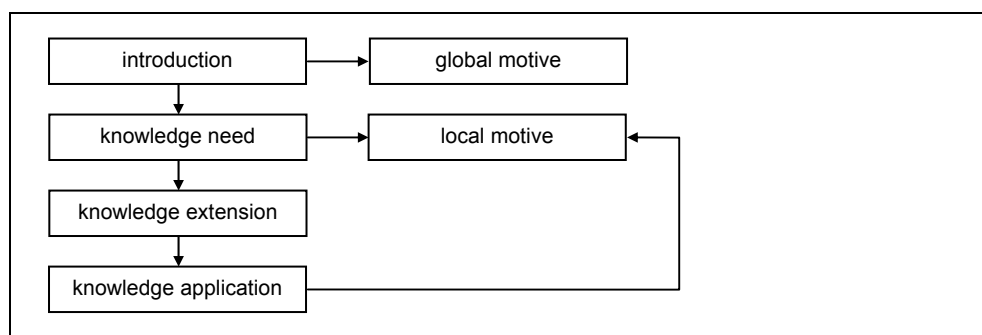


Figure 4 – The didactical structure of a PLON unit.

### Didactical frictions

Although the unit follows this logical phase structure, 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 (such as making the use of safety belts and crash helmets obligatory by law in 1975), and that those measures have caused a considerable decrease in the number of traffic casualties. Students are asked to infer this from the diagram presented in Figure 5, showing the number of traffic casualties for different categories of traffic participants over the years.



Figure 5 – Two pictures from the PLON unit *Traffic and Safety* : the number of traffic casualties over the years (left), and the motion of the car driver’s body when wearing a safety belt (right). The physics involved is summarised by the (empirical) equation  $F \cdot s = \frac{1}{2} \cdot m \cdot v^2$ : given a certain initial speed  $v$ , the safety belt lengthens the displacement  $s$  of the body and thus reduces the force  $F$  exerted on the body during a collision. The 1975 marker and trends (dotted lines) have been inserted by the author.

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, as the unit is about braking and colliding. 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.

The unit concludes with the fourth phase of applying the extended physics knowledge about force and motion in situations the knowledge was extended for. So, thoughtful decision making on traffic behaviour, triggered by the question whether the use of safety belts and crash helmets should be a legal obligation or a matter of individual responsibility. And by the question about the students' own (prospective) behaviour: what would *you* do? This fourth phase expresses a consequence of the now-called 'context-concept approach' to teaching and learning science: when starting from a specific context for which science knowledge has to be extended, there is an 'obligation' to address the context again in the end, now to see whether the extended science knowledge is indeed helpful for solving a problem or for decision making on either a social or a personal level.

The above criticism of the unit in terms of the two didactical frictions, 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 knowledge 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 socio-scientific issues, and, secondly, that science content has a personal and/or social relevance in enabling thoughtful decision making about everyday 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 thoughtful 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 a corroborative effect, as now students realise how large the forces acting on a body during a collision can be.

Changing the focus of the unit from a practical to a theoretical orientation will, of course, also take away its scientific literacy flavour.

### **Findings**

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 with a positive impact on their motivation, 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 (Wierstra, 1990; Bennet *et al.*, 2005), although, certainly in the case of PLON, it is not very clear whether this is caused by the context-based or by the activity-based approach which are both prominent in the PLON units. The second assumption, however, has not appeared to be that simple. It appears that the PLON curricula do not differ from 'traditional' curricula with respect to the students' cognitive learning outcomes (Wierstra, 1990; Eijkelhof, 1990). Moreover, it appears difficult to have students use their acquired conceptual science knowledge in practical decision-making situations (Fleming, 1987; Ratcliffe, 1997), 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 findings, on the one hand, seem to reflect the above outlined didactical frictions concerning why which science knowledge is needed, and, on the other hand, show the effects of a lack of attention for the students' preconceptions and conceptual development at that time.

## **2 A problem-posing approach**

The next step in my history of curriculum development is the problem-posing approach as a solution for the didactical frictions identified in the PLON units, although it has to be remarked that the process did not proceed as linear as this paper suggests: the didactical frictions were identified in retrospect, and the same applies to the problem-posing approach as being a solution for that problem. This problem-posing approach can be seen as the theoretical framework for describing, analysing and developing context-based teaching-learning sequences (Kortland, 2007).

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), resulting in a more or less general 'didactical structure' for the teaching-learning of specific topics (Lijnse & Klaassen, 2004). This didactical structure was already used in the previous section to analyse the didactical quality of the PLON units: 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.

To this four-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.

The unit *Radioactivity* (Klaassen, 1995) will serve as an example. The generalised didactical structure of this unit is outlined in Figure 6. The first phase induces a global motive for the study of this topic by referring to different kinds of applications of radioactive substances, e.g. in health care. In the second phase this global motive is narrowed down to wanting to solve a practical problem, referring to the 'actual problem' of certain food stuffs (such as milk and spinach) in the Netherlands becoming radioactive after the Chernobyl nuclear reactor accident. The students think they know how to make something radioactive: just put it near to a radioactive source for a while. Such experiments, however, do not appear to 'work', thus giving rise to the question: 'How to make something radioactive?' This question drives the students' learning process during the next two phases, in which students extend their existing pre-knowledge towards a macroscopic theory of radioactivity and apply their extended knowledge to solve the practical problem of how to make something radioactive (and, of course, how not). During this learning process, quite naturally, all kinds of questions might emerge that could be summarised as 'What exactly *is* radioactivity?' This question represents a theoretical problem, to be solved in the subsequent phases by having the students extend their macroscopic theory towards a microscopic theory of radioactivity.

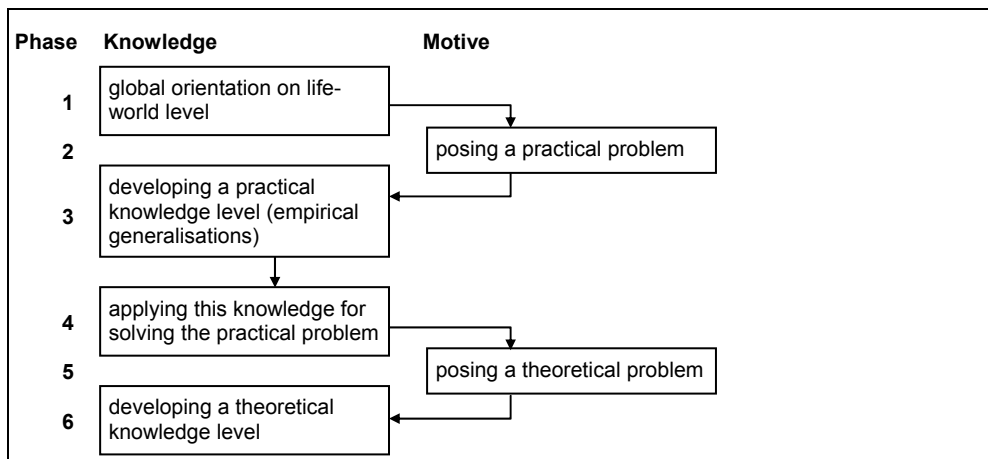


Figure 6 – The generalised didactical structure of the unit about radioactivity, dealing with a practical problem from which a theoretical problem emerges in a natural way.

### Findings

The problem-posing approach – in retrospect – can be considered as a solution to the problem of didactical frictions identified in the PLON units. It appears that students do experience a (more) coherent learning process through induced global and local content-related motives (Klaassen, 1995; Vollebregt, 1998; Kortland, 2001).

There are, however, some new problems. First of all, there is a problem for the teacher in making the teaching-learning process explicit for the students (in order to remind them why they are learning what), and using the students' input productively (e.g., to help them formulate the questions for further investigation on the basis of their pre-knowledge). From the viewpoint of the designer, the didactical structure is useful as a design tool, be it in a

limited way. The main problem for the designer is in establishing global and local content-related motives as an elaboration of the generalised didactical structure for a new topic.

### 3 Learning in Authentic Practices

The problem for the designer mentioned at the end of the previous section was thought to be solved by turning to the idea of learning in authentic practices – the final step in my history of curriculum development, at least for the time being. An idea that, again, had been worked out to some extent before it was seen as a solution to this problem.

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 joint goal of solving a specific science/technology-related practical problem by means of a joint type of characteristic procedure leading to a solution of such a problem. With a view to a problem-posing approach this goal could serve as a global motive for actively involving students in an appropriate communal practice. The characteristic procedure could first of all serve as an advance organiser (Ausubel, 1968), providing students with a view on the direction of their prospective learning process. Secondly, the characteristic procedure could serve for inducing local motives for knowledge extension, as this is a procedure in which scientific/technological knowledge, skills and attitudes do come in naturally and therefore unquestioned. It will be obvious, however, 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. It is therefore a matter of devising 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*, 2006).

Such a didactical structure is visualised in Figure 7, showing the already familiar four phases and highlighting the authentic practice as a source of inspiration for the global motive, the content-related local motives for knowledge extension – visualised by reversing the direction of some of the arrows in comparison to those in Figure 4. Moreover, the existence of a characteristic procedure as the backbone of an educationalised authentic practice requires two 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):

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

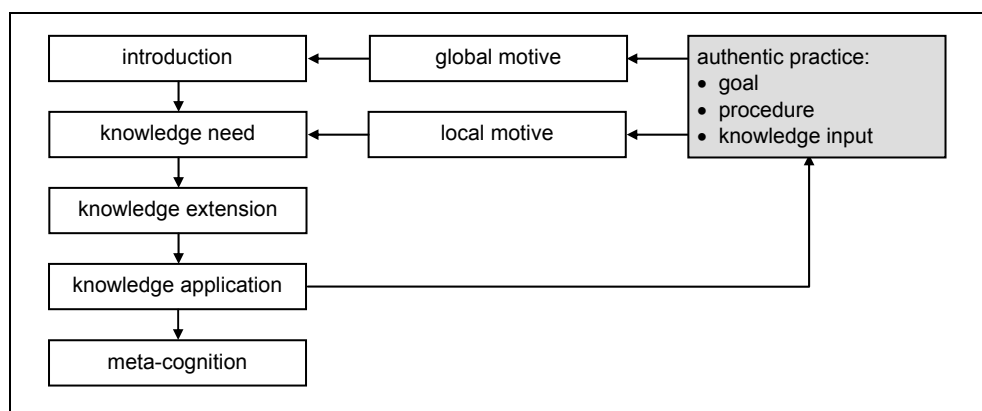


Figure 7 – The didactical structure as inspired by an authentic practice.

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 (West-



broek, 2005) as outlined in Figure 8. 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 students' intuitive notions about a characteristic procedure as an advance organiser.

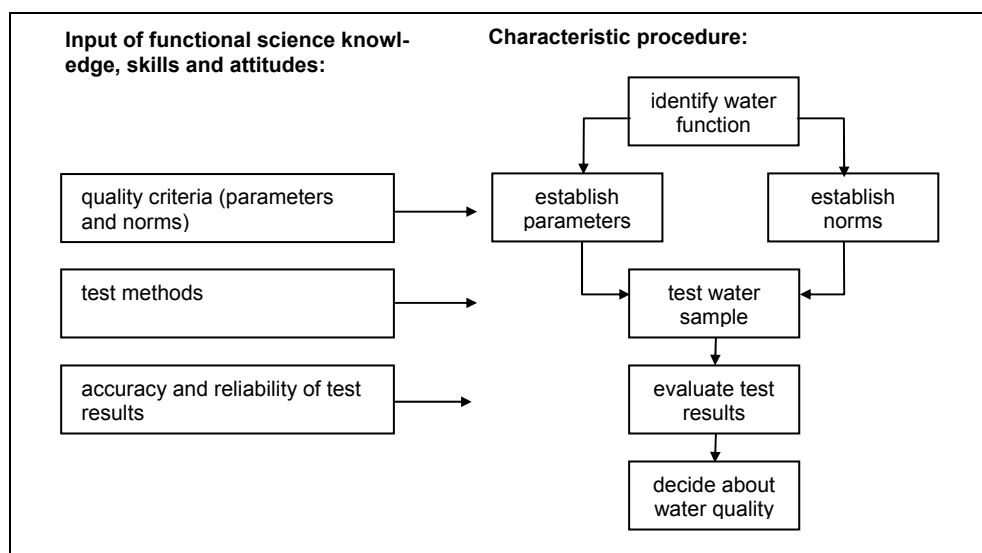


Figure 8 – Characteristic procedure in the unit about water quality, with its input of functional science knowledge, skills and attitudes.

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 pa-

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.

### **Findings**

Learning in authentic practices was considered to be a solution to the problem of inducing a global motive and content-related local motives for knowledge extension in a problem-posing approach. It appears that students do experience a coherent learning process: they do recognise and appreciate the goal of the authentic practice (global motive), they do have a sense of direction because of their intuitive notions about the characteristic procedure (advance organiser) and they do recognise the functionality of the required knowledge input into this procedure (local motives) (Westbroek, 2005).

There are, however, some new problems. First of all, there still is – as was the case in the problem-posing approach – a problem for the teacher in making the teaching-learning process explicit for the students and using the students' input productively. For the designer, the didactical structure is useful as a design tool: there appears to be a mutual reinforcement between the problem-posing approach and learning in authentic practices. 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 about decision making on environmental issues (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 functionality 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 an advance organiser that gives them a sense of direction for their learning.
- The science knowledge, skills and attitudes that are needed in order to be able to act effectively in this practice are such that students are initially aware of them in broad outline, though not in their 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.

### **Design tool**

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 an 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 9.

- 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 these 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 knowledge involved and their intuitive notions about a characteristic procedure. Students come to realise that, for solving this exemplary problem along the lines of the characteristic procedure, 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) meta-cognitive 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.

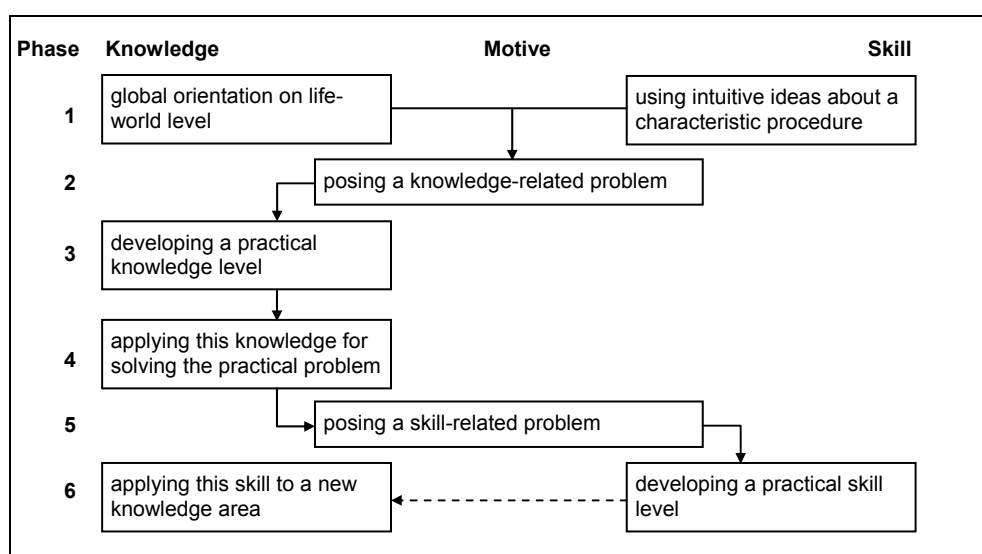


Figure 9 – Generalised didactical structure of teaching-learning sequences inspired by an authentic practice.

### Authentic practices and scientific literacy

The problem with (educationalised) authentic practices is their rather one-sided character: they mainly deal with professional/vocational practices, generally related to 'making and/or testing stuff' (such as drinking water). The solution to this problem is expanding the idea of learning in authentic practices to life-world practices and scientific practices. Both types of practice relate to scientific literacy. Life-world practices could refer to decision making on socio-scientific issues, and scientific practices could support this by knowledge about the nature of scientific knowledge as a prerequisite to such decision making.

The characteristic procedure and its required science knowledge input in such cases could be the decision-making procedure for not too complex issues as shown in Figure 10, adapted from a teaching-learning sequence about decision making on environmental issues (Kortland, 2001). The students' intuitive familiarity with this procedure can be used as an

advance organiser. The local motive for knowledge extension (or the questions for further investigation) can be induced by having the students first do their decision making on the basis of their pre-knowledge about the issue. This will, quite probably, give rise to either disagreement between students at the whole-class level about the properties and characteristics of the alternatives, or admitting that such knowledge is (still) lacking. After having extended their knowledge in the required direction, they can, now successfully, redo their decision making. And in the end it is for the students to decide whether or not to act upon the outcome of their decision making, and monitor scientific and technological developments that might change the original decision-making situation.

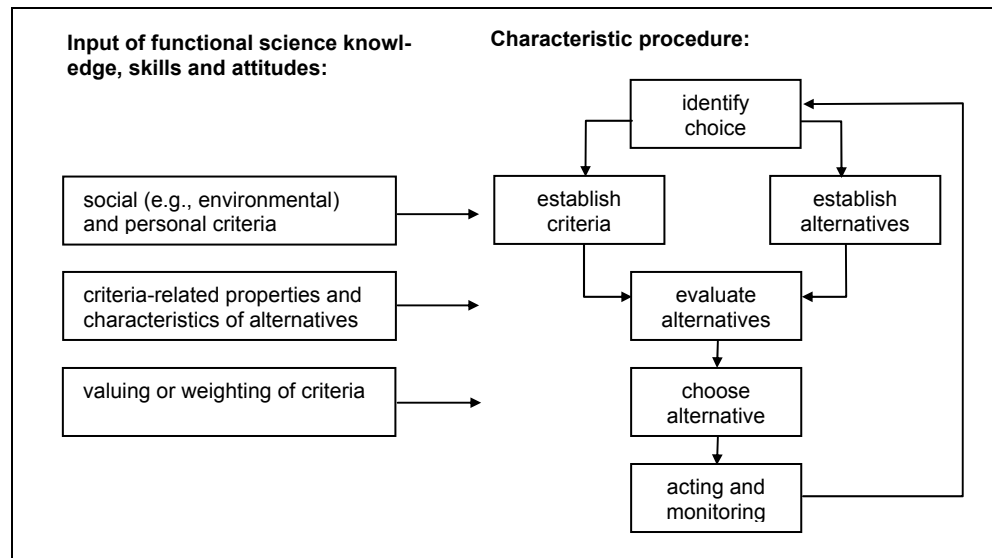


Figure 10 – General decision-making procedure with its input of functional science knowledge, skills and attitudes.

The decision-making procedure outlined in Figure 10 might also be used for choosing between competing scientific theories, such as the controversy between Newton and Kepler about explaining motion, and between Newton and Huygens about the character of light. In this case the criteria are of a scientific nature, such as simplicity, generality and adequacy.

### Conclusion

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 problem-posing didactical structures that do not display didactical frictions about the motive for extending science knowledge and the nature of that knowledge. So, useful for designing teaching-learning sequences in which students have a content-related view on why they are going to learn what, elaborated by a global motive, an advance organiser in terms of a characteristic procedure, and local motives for knowledge extension in terms of functional input of science knowledge into this procedure. Educationalising authentic practices, however, is not unproblematic: it is necessary to 'translate' the global motive, to discover the characteristic procedure and to simplify the functional science knowledge input – adapted to the age and ability level of the students. And it would be necessary to expand the idea of 'authentic practice' to personal decision making on socio-scientific issues.

The focus of this paper has been on the didactical quality of a teaching-learning sequence in terms of a coherent, and for the students logical didactical structure. The generalised didactical structures as presented in Figures 6 and 9 and the characteristic procedures in Figures 8 and 10 could serve as design tools. There are, however, a number of pitfalls to avoid:

- Wrong global motive – Although students will recognise the importance of the goal of an authentic practice, this does not answer their question of 'Why should we learn this?'
- Wrong sequence – The general sequence of context > concept > context is easily reduced to context > concept (thus reducing the context to a mere starter) or to concept > context (thus reducing the context to some kind of an appendix).
- Wrong life-world problem – The unit deals with an issue that can be solved with com-

non-sense knowledge, and for which therefore no extension of science knowledge is needed.

- Wrong science content – A (large) part of the knowledge extension phase of the unit concerns non-functional science knowledge.
- Wrong conceptual development – The teaching-learning activities make no productive use of the students' pre-knowledge and pay no attention to the conceptual problems students might have.
- Wrong closure – The end of the unit provides no meta-cognitive (decision-making) tools for tackling comparable issues.
- Wrong teaching-learning activities – The teaching-learning activities require no active involvement and thinking of the students.
- Wrong age group – The unit is meant for students over 15 years of age, who have chosen physics or chemistry in upper secondary education. Such units are, of course, useful, but it has to be noted that they do not address students below the PISA age limit and that they do not address *all* students.

In the light of the above, the aims of scientific literacy as stated in the beginning of this paper could be qualified as rather ambitious, requiring an extensive focussed design research effort. In this effort, it would not be a bad idea to try to learn from past experiences instead of reinventing the wheel. With that in mind, let us now briefly review the IPN unit about the 'zero emission vehicle'. Since the 1970s, technology and data have changed. What is needed is an update of context and didactical structure. As far as the context is concerned, the electric cars featuring in the unit (see Figure 11) can be replaced by something more flashy, while also the sustainable alternatives for producing electricity should be addressed more explicitly (see Figure 12).



Figure 11 – An electric car from the 1970s.



Figure 12 – An update of the context.



As far as the didactical structure of the unit is concerned, the functionality of the science knowledge seems to be (still) adequate. The unit even offers the possibility of a problem-posing approach in which the learning process is driven by questions, preferably formulated by the students themselves – triggered by a specific teaching-learning activity. The unit provides an example of such an activity. In one of the trials of the unit, the students were asked to produce a list of pros and cons of the electric car. At the whole-class level students list as pros that the electric car produces no exhaust gases, is environmentally friendly and uses little energy. On the other hand they list as cons that the electric car requires more power plants and uses a lot of energy. From this, it is obvious that students either disagree or do not yet know enough about the environmental impact of electric cars, thus giving rise to (their own) questions for further investigation in the remainder of the unit. So, a problem-posing approach 'avant la lettre'?

### Acknowledgement

The author wishes to thank Kees Klaassen, Piet Lijnse, Harrie Eijkelhof, Astrid Bulte and Hanna Westbroek, 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.

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