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Special Issue

Didactical structures as an outcome of research on teaching–learning sequences?

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This paper describes 'didactical structures' as a possible outcome of research on teaching–learning sequences. Starting from an explicit didactical perspective, in this case a so-called problem-posing approach, the research emphasis lies on the didactical quality with which this particular perspective can be put into classroom practice in the teaching and learning of a certain topic. This is done by a process of developmental research, in which a research scenario, as a detailed prediction and theoretical justification of the hypothesized teaching/learning process, plays a crucial role. Three empirically supported resulting didactical structures are described, developed for the solution of different content dependent didactical problems. By reflection on these structures, more general structures and features are abstracted that enable transfer of the outcomes to the didactics of other topics. Finally, it is discussed what these results can offer to the development of a more general didactical theory.

Why do we need them?

More or less as a follow-up to lots of studies identifying students' conceptions about many concepts, much research has been done on teaching–learning sequences that sought to develop research-inspired improved ways of teaching the topics under concern (Driver 1989, Driver and Oldham 1986, Leach and Scott 2002, Lijnse 1994). However, to our opinion, it is doubtful whether as yet such research has indeed made available preferred ways of teaching a topic, or well-argued comparisons of particular teaching approaches.

This can be concluded from the fact that in the international research literature only little information is published about teaching–learning sequences (Gabel 1994, Millar et al. 2000, Tobin and Fraser 1998); the more so as the developed teaching materials are mostly only available in local languages. If published at all, then details about them can often only be obtained from publications in local journals aimed at teachers. A case in point is, for example, the introductory teaching of a particle model. Even though much work on this topic has been done in several countries, one cannot say that a common research-based opinion has resulted (CLIS 1987, Meheut and Chomat 1990, Johnston 1990, Lijnse et al. 1990, Vollebregt 1998).

What seems to be apparent from much of the literature is that science education research does not so much aim at developing content specific didactical knowledge, possibly to be described as small-scale theories, but much more at contributing to (if only by simply applying) general educational and/or psycho-

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logical theories (see, for example, Duit and Treagust 1998). We regret this 'flight away from content' because thereby a level is skipped that we consider necessary for making *didactical progress*. The missing level is that of describing and understanding what is, or should be, going on in science classrooms in terms of content-specific interactions of teaching–learning processes, and of trying to interpret them in terms of *didactical theory* (Lijnse 2000). If one attempts to interpret what is going on in science classrooms directly in terms of such general (learning) theories, one immediately faces the problem that, on application, such theories only result at best in heuristic rules. Such rules simply cannot guarantee that the teaching process that is supposed to be governed by them will have the necessary *didactical quality*.

However, research on actual teaching–learning sequences is seldom published in enough detail to make this problem really come to the fore (for example, Leach and Scott 2002). Probably because it is generally felt that it is the necessary personal freedom and competence of teachers that make sequences work in practice. The more so as it is mostly believed that, even given certain aims, there exists no 'best way' of teaching a topic.

Although we do agree to a large extent to these opinions, we also believe, however, that such points of view underestimate the difficulty of putting more general theoretical ideas into adequate practice and, consequently, that we should not overestimate the competence of teachers in this respect (see, for example, Klaassen and Lijnse 1996). And, apart from that, although a best way of teaching a topic may indeed be an illusion, we do think that some ways are better than others; and therefore that it is worthwhile to search for evidence of how and why that is the case and for means that enable to express and discuss the *didactical quality* of such teaching sequences and situations. In this paper it is argued that the concept of 'didactical structure' might provide a further step to foster such deeper discussions about didactical advantages and disadvantages of particular ways of teaching a topic. Therefore, we will first describe three examples of didactical structures that have resulted from our research on teaching–learning sequences and discuss, finally, to what extent such structures might help us in communicating more accurately about their didactically relevant aspects.

Views on science and science teaching and learning

In general, the design of teaching–learning sequences should start by making explicit and justifying one's view on teaching and learning, on science and on science education (Millar and Osborne 1999). The reason for this is, of course, that neither education nor science are value-free processes and, thus, that we can only communicate and discuss our research results properly if they are placed within and judged from the value-laden context in which they are obtained. These value-laden choices are not only reflected in the goals that one wants to reach, but also in the ways they are aimed at.

For the design of teaching sequences, for example, in principle it may make a difference whether one starts from a receptive, behaviouristic, discovery or information-processing view on learning, to name just a few influential views from the recent past (Duit and Treagust 1998); even though such differences may, in didactical practice, turn out to be much smaller than expected. Regarding views on learning, much attention has been drawn recently by constructivism. To our opinion, the didactical relevance of that view boils down to the rather trivial phrase that 'new knowledge is constructed on the basis of already existing knowledge' (Ogborn 1997). As such, this view does not relate directly to a view on teaching as the construction process of the learner always takes place, irrespective of how he/she is being taught. However, if one wants to prevent a learning process that results too quickly in a *forced* concept development full of misconceptions, or, in other words, if one adopts the view that teaching should result in something like real understanding, it seems necessary to allow students ample freedom to use and make their constructions explicit; for example, by means of social interactions with the teacher and/or peers (freedom from below), and at the same time to carefully guide their construction process in such a way that it results in the aims that one wants to reach (guidance from above).

Finding an adequate balance between this necessary freedom from below and the equally necessary guidance from above lies at the heart of our didactical research. It means that one tries to guide students in a *bottom-up* teaching–learning process, starting from *common ground* (i.e. starting from shared, and known to be shared, ways of thinking about the world), by designing teaching activities that are to gradually create places in students' conceptual apparatus for the concepts and skills one wants to teach to occupy. In that sense, we can give content to the phrase 'construct new knowledge on the basis of already existing knowledge'.

At first sight, this view seems to represent nothing new, as is clear from many reports about 'constructivist science teaching' (Leach and Scott 2002, Scott et al. 1992). In our work, however, we differ in two major aspects from these reports. Although we take 'educational constructivism' in the aforementioned sense as a first starting point, we do not adhere to the 'alternative framework' movement. In our view, students' beliefs about their experiential world are, in general, largely correct, which implies that, if properly interpreted, we can always find common ground to start from in our teaching process (Klaassen 1995, Klaassen and Lijnse 1996). As far as cognitive learning is concerned, we think it best to think of science learning as a process in which students, by drawing on their existing conceptual resources, experiential base and belief system, come to *add* to those (with accompanying changes of meaning).

What we think needs to be added to this picture, as a second starting point, is that if this process is to make sense to them, students must also be made to *want* to add to those. Or, in other words, students should at any time during the process of teaching and learning see *the point* of what they are doing.[1] If that is the case, the process of teaching and learning will probably make (more) sense to them and it then becomes more probable that they will construct or accommodate new knowledge on grounds that they themselves understand. An approach to science education that explicitly aims at this, we call *problem posing*. The emphasis of a problem-posing approach is thus on bringing students in such a position that they themselves come to see the *point* of extending their existing conceptual knowledge, experiences and belief system in a certain direction. Thus formulated, the second starting point also seems rather trivial, and indeed it is. Since in themselves both starting points do not give any further detailed didactical guidance, the real *non-trivial* didactical challenge lies, as already mentioned, in the quality with which they can be put into practice. The more so as such an approach asks for a considerable change in didactical contract (Tiberghien 2000) as compared with what teachers and students are mostly used to.

In correspondence to this and in analogy to what Freudenthal (1991) writes about mathematics, we may say that we see science as a human activity and that, consequently, science teaching should guide students in '*scientificalizing*' their world, instead of trying to transfer scientific knowledge as a ready made product. Freudenthal speaks in this context about a process of *guided re*invention that students have to participate in, adding that for its design it might be quite inspiring to look into the history of invention.

Our point of view of developing a problem-posing teaching–learning approach along these lines thus asks for a thorough didactical analysis of common sense and scientific knowledge, as well as of their relation. How can we design a conceptual teaching pathway that is divided in such steps that, in a teaching situation, students are meaningfully able and willing to take them, building productively on what they already know and are able to? Can we make students ask or value questions that on the one hand make sense to them and that, on the other, ask for the development of (possibly adapted) new ideas and scientific concepts to be taught that provide an answer to their questions?

That means that, for them, the concepts to be reinvented will function for a particular purpose, and that the reasons for their construction and acceptance are directly derived from that functioning. In doing so, apart from being guided, knowledge construction within this problem-posing approach is, in a sense, similar to the process of professional knowledge construction within science itself. Knowledge is (guidedly) constructed for a certain purpose. And it is accepted by those who construct it to the extent that it functions productively for that purpose.

In our opinion, we may roughly distinguish four main purposive orientations in which scientific knowledge may function: practical (learning to cope in everyday live); theoretical (learning to understand nature); technical/industrial (learning to design technical artefacts or industrial products); and societal (learning about science and society). These purposive orientations are related to different views on (the relations of) science, technology and society, and thus does their possible adoption in science curricula require an explicit view on science education that has to be matched with a particular view on the social and pedagogical role of education itself. For the design of teaching–learning sequences it means, in general, that such sequences will be developed within one or more particular orientations that are to be made functional for students.

Methodology

Before presenting some results of our research on teaching–learning sequences more explicitly, we first want to say some words about our methodology (Gravemeijer 1994, Klaassen 1995, Lijnse 1995, 2003). In our work, we may distinguish between three levels of working. We develop *teaching–learning materials* for teachers and students. However, we do not just write them rather intuitively as textbook writers usually do. In fact, we develop them in parallel with a *scenario.* This scenario *predicts* and theoretically *justifies* in detail the teaching–learning *process* as it is *expected* to take place and *why* it is expected to happen in that way. This relates in particular to the interaction of teaching and learning activities. Thus we may consider the scenario to be a *hypothetical* domain-specific didactical theory (*in statu nascendi*) that can be tested and revised. In developing that scenario we take great care in making a thorough didactical analysis of the content to be taught and in trying to interpret teaching activities through the eyes of the students. We also put much emphasis on the connection between the teaching activities and on the role of the teacher in making these activities 'work'. Does the previous activity really prepare for the next activities, and is the next one really sufficiently prepared for by the previous activities. Or, in other words, can the expected teaching–learning *process* really be considered as *coherent* from the perspectives of students and teacher?

The development of a scenario asks for a mixture of didactical analysis, intuition and creativeness, for the use of teacher craft knowledge as well as of theoretical heuristics and reflection. Gravemeijer (1994) writes in this context about 'theory-guided bricolage'. In fact, in developing a scenario, we precisely try to fill the didactical gap we have already mentioned.

In the try out of the teaching sequence, the scenario functions as a detailed research *instrument* that guides our observations and interpretations of the teaching–learning process. An adapted version of the scenario is used in our teacher preparation. Such an adaptation appeared to be necessary to reduce the risk that the teacher may experience the scenario too much as a straight jacket. After one or two cycles of testing, the scenario and teaching materials may have reached the stage that they can be considered 'good enough for practical purposes' (i.e. for teaching practice).[2]

Then the inter-related conceptual and content-related motivational pathway (i.e. the main steps to be taken and stages to be gone through by teacher and students), as derived from the final scenario, are reflected upon and summarized in what we may provisionally call a possible *didactical structure* for the topic at hand. For this process of abstraction we have no definite *a priori* criteria, as it concerns a process of 'theory in the making'.

In our empirical procedure, we think it is essential not only to focus on the learning of the students, but in particular also on the learning of the teacher. In fact, this could also be reflected upon in terms of a didactical structure of the content-specific didactics at hand. A theoretical reflection on both, in relation to the scenario as developed and the chosen starting points, leads to the final *didactical learning process of the researcher.* An adequate report of that may be considered the main scientific outcome of our didactical research, in the sense that it should reflect progress in didactical knowledge that is both theoretically grounded and empirically supported.

Examples of empirically tested didactical structures

Before we describe some examples,[3] it should be kept in mind that the presented structures are a short-hand description of the respective scenarios and teaching materials. In fact, it can be questioned to what extent they are really comprehensible for those who are not familiar with the latter. Nevertheless, they are attempts to communicate essential didactical aspects; that is, how research-based sequences attempt to solve a particular didactical problem. At the content-specific level they represent feasible empirically tested new answers to practical didactical problems. These answers are developed within an explicit didactical perspective, as regards purposive orientations and views on teaching and learning science, and can thus be discussed and judged on their consistency and appropriateness from that perspective. In that sense they are to represent examples of didactically new ‘good practices’, in which not only results of relevant educational research are taken into account, but also extended and enriched at the level of didactics.

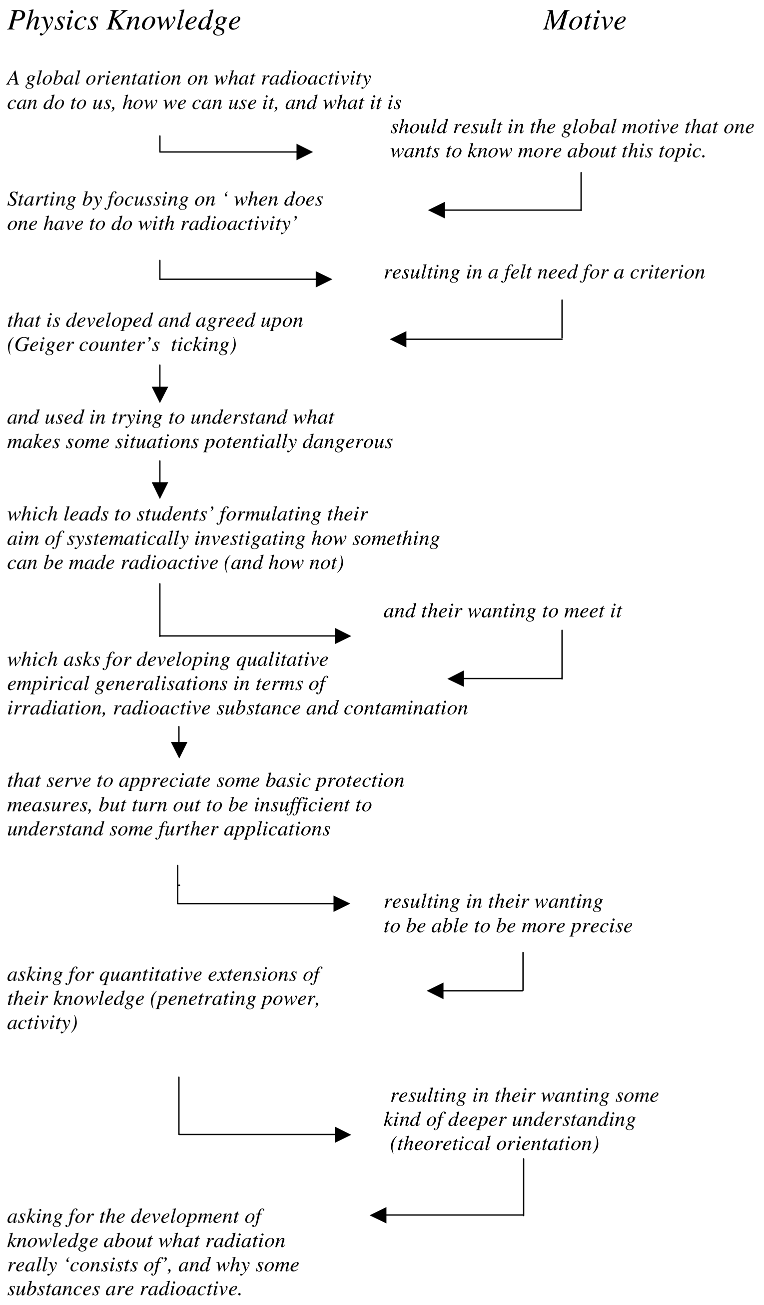
An introduction to radioactivity

A first example has to do with an introduction to radioactivity within the regular compulsory curriculum for lower ability students of age 15.[4] A lesson sequence of approximately 12 lessons (of 50 minutes each) was designed, primarily within a *practical* orientation. Figure 1 summarizes the final resulting structure of our approach. This structure consists of two columns, the first focusing on the knowledge to be taught and the second on the motives to be developed that should drive the learning process.

Our first goal was to design a teaching approach that would not result in the usual conceptual confusions regarding radioactivity (Eijkelhof 1990, Klaassen 1995). The structure therefore starts at students’ life-world knowledge about radioactivity. At this level radioactivity is something mysterious and vague, as no difference exists yet between what is meant scientifically with the terms ‘radioactive substance’ and ‘radioactive radiation’, so that also no distinction can be made between ‘irradiation’ and ‘contamination’. The first main didactical problem then consists of making it meaningful for students to learn about these distinctions. Therefore, their life-world knowledge is productively used in coming to their formulating a, within the chosen context, main practical problem (i.e. ‘how can one make something radioactive?’). Students come to formulate this question when their expectation that something that is ‘irradiated’ (e.g. an apple placed for a long time in the neighbourhood of an object that according to them ‘is radioactive’) will itself have become ‘radioactive’ turns out not to be true.

The bottom-up character of the sequence is further reflected in the fact that it does not start from theoretical knowledge about atoms and nuclei (nor necessarily ends with it), as is usual in textbooks for this topic, but, in order to tackle the problem, first develops a level of empirical generalizations, in terms of ‘irradiation’, ‘radioactive substance’, ‘radiation’ and ‘contamination’, that are sufficient to understand the potential dangers and corresponding protection measures in some situations.

The problem-posing character of our approach is, in particular, reflected in the interrelation of the motives and knowledge that are to be developed. A general characteristic of our approach is the role of a ‘global motive’, relating to the sequence as a whole, in connection with a series of ‘local motives’ that motivate its main phases. It should be noted that the main focus of the structure under concern lies on the transition from the life-world level to the qualitative and quantitative levels of empirical generalizations, by means of making students coming to pose themselves a, for them, meaningful main practical problem that they want to solve. It is this characteristic together with the subsequent way in which that problem is then solved that can be considered a main didactical result, when compared with other approaches in which the conceptual difficulties involved are either neglected or inappropriately tackled.



Physics Knowledge

Motive

A global orientation on what radioactivity can do to us, how we can use it, and what it is

should result in the global motive that one wants to know more about this topic.

Starting by focussing on ' when does one have to do with radioactivity'

resulting in a felt need for a criterion

that is developed and agreed upon (Geiger counter's ticking)

and used in trying to understand what makes some situations potentially dangerous

which leads to students' formulating their aim of systematically investigating how something can be made radioactive (and how not)

and their wanting to meet it

which asks for developing qualitative empirical generalisations in terms of irradiation, radioactive substance and contamination

that serve to appreciate some basic protection measures, but turn out to be insufficient to understand some further applications

resulting in their wanting to be able to be more precise

asking for quantitative extensions of their knowledge (penetrating power, activity)

resulting in their wanting some kind of deeper understanding (theoretical orientation)

asking for the development of knowledge about what radiation really 'consists of', and why some substances are radioactive.

Figure 1. A didactical structure for a problem-posing approach to the introduction of radioactivity.

In the presented didactical structure we may distinguish the following phases:

- Phase 1: orienting and evoking a global interest in and motive for a study of the topic at hand.

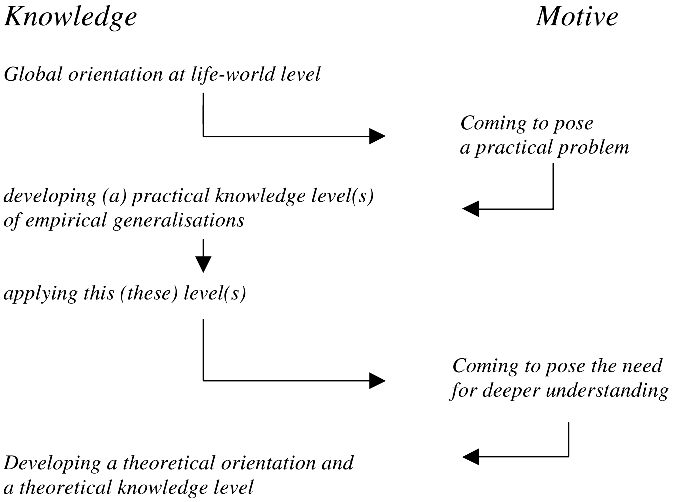


Figure 2. Level structure of an introduction to radioactivity.

- 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.
- Phase 5: creating, by reflecting on the developed knowledge, a need for a theoretical orientation
- Phase 6: developing within this orientation further theoretical knowledge.

We remark that phases 2 and 5 represent one of the main points of a problem-posing approach. Such phases appear 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.

These phases relate to particular didactical functions that have to be fulfilled in such a way that they assure the necessary coherence in the activities of the students. This asks from the teacher to not only function at a cognitive level, but also regularly at a didactical meta-cognitive level. It is this latter teaching activity that has appeared not only to be very unusual for teachers but, in spite of the examples in the scenario, also very difficult.

In reflection on the structure of figure 1, we may also come to a more general and therefore probably more transferable representation of the didactical structure.

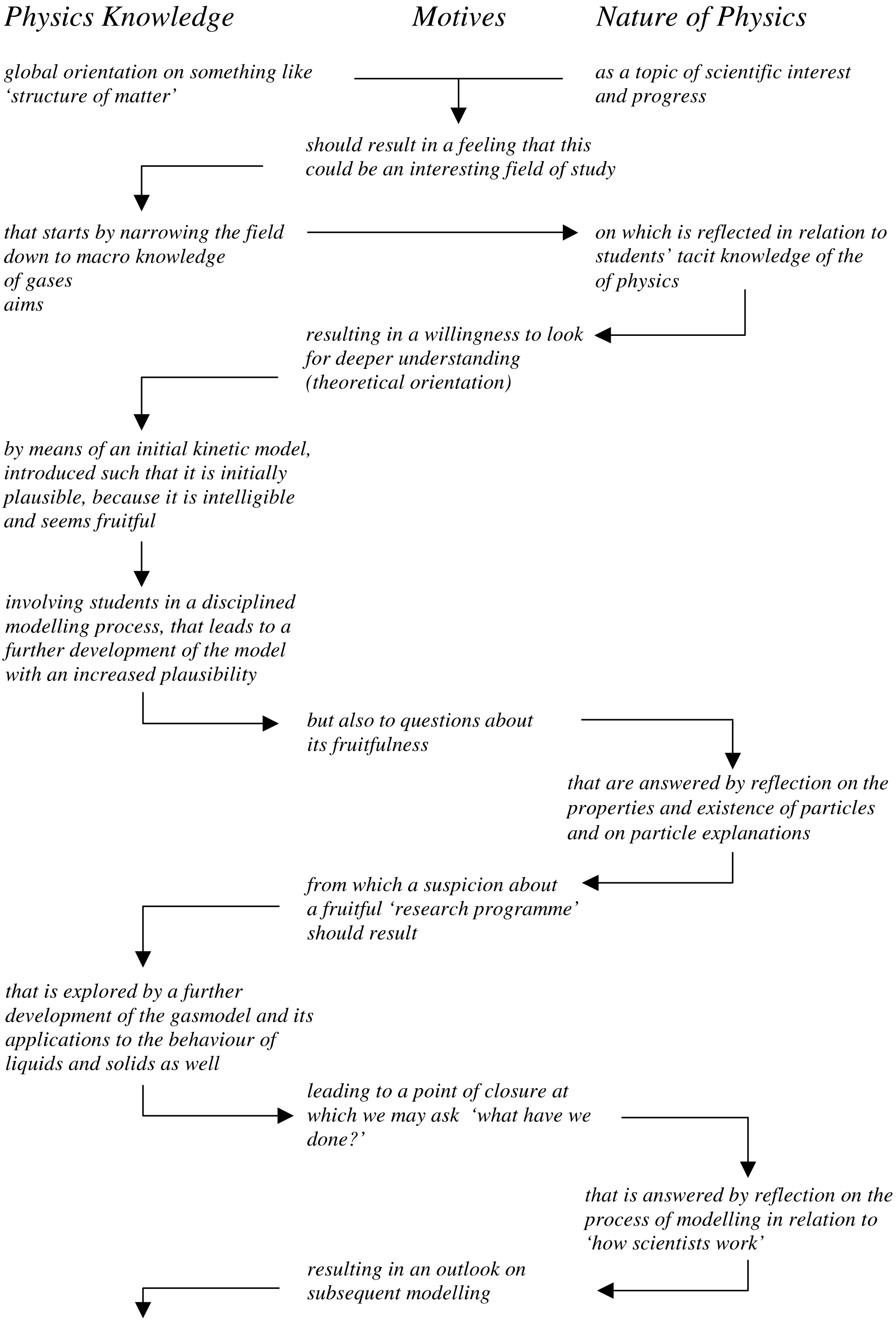
This description focuses more on characteristics of the knowledge involved, be it still in a rather global way. In fact, three ways of talking about radioactive phenomena are described in figure 2, each with its specific concepts and associated ways of explaining. The didactical challenge is to make learners move meaningfully downwards through this three-level structure by making them see the point of using and developing new concepts, in order to meet new explanatory interests. The transferability of the structure of figure 2 lies in the fact that it provides a way of thinking that may also be applicable to the development of a similar structure for the teaching of other topics

The inter-related teaching of an initial particle model and the nature of particle models

A second example of a didactical structure that resulted from a tested scenario can be taken from the work of Vollebregt (1998). In a sequence of nine lessons (of 65 minutes per lesson), Vollebregt designed a problem-posing approach for the introduction of an initial particle model as part of the compulsory physics curriculum for higher ability students of age 16. Thus, in her work, the development of a *theoretical* orientation as well as the subsequent development of theoretical model-based knowledge deal with the standard problem of explaining macroscopic properties of matter in terms of a submicroscopic model in a, for students, meaningful and understandable way. Much research has shown this to be a didactically difficult challenge, which we do not claim to have solved. However, we do claim that we have achieved more insight into a possible didactical way out.

In the sequence, first, a theoretical orientation has to be evoked. As a starting point for that we have chosen for a previously taught descriptive knowledge level with respect to the macroscopic behaviour of gases, which is then problematized on the basis of the idea that in physics one tries to come to ever deeper understanding by asking evermore ‘why and how come’ questions. This latter idea can be interpreted as a still rather vague and undifferentiatedly worded element of a ‘life-world level’ with respect to the nature of physics, which is used here productively together with the rather obvious idea that the ‘machinery of things’ can often better be understood if one looks for what they are made of. It is the difficult task of the teacher to use these ideas together with what students already know about the behaviour of gases to guide them in coming to ask the question of what gases actually are made of, and in then presenting a first intelligible germ of a particle model, in terms of criss-cross moving small balls, that puts students on the right track for a further fruitfully guided modelling process in which the germ is extended into a first ‘real’ particle model (Lijnse 2000). For instance, the initial particle model is framed in terms of moving balls. This model is somehow further developed by students in order to explain macroscopic gas laws (e.g. Boyle’s law). But also this extended model is still formulated in terms of balls. The *prima facie* plausible methodological maxim to not assume more than necessary (Occam’s razor) can then be invoked to make students wonder whether the particles need to be balls and, more generally, what properties can be attributed to the particles on what grounds. In doing so, after a while, students easily come up with the question whether their modelling process is leading to the ‘right’ answer, which provides the natural opportunity to go further into methodological, epistemological and ontological aspects of what they have been doing. Thus, in reflection, some ‘rules of the modelling game’ can be made explicit and illustrated, which could perhaps be interpreted as part of a kind of ‘descriptive’ level of knowledge about the nature of physics/modelling.

This structure thus shows the interesting feature of two distinguishable, although reflectively coupled, learning processes that, by means of the middle



global orientation on something like 'structure of matter'

as a topic of scientific interest and progress

should result in a feeling that this could be an interesting field of study

that starts by narrowing the field down to macro knowledge of gases aims

on which is reflected in relation to students' tacit knowledge of the of physics

resulting in a willingness to look for deeper understanding (theoretical orientation)

by means of an initial kinetic model, introduced such that it is initially plausible, because it is intelligible and seems fruitful

involving students in a disciplined modelling process, that leads to a further development of the model with an increased plausibility

but also to questions about its fruitfulness

that are answered by reflection on the properties and existence of particles and on particle explanations

from which a suspicion about a fruitful 'research programme' should result

that is explored by a further development of the gasmodel and its applications to the behaviour of liquids and solids as well

leading to a point of closure at which we may ask 'what have we done?'

that is answered by reflection on the process of modelling in relation to 'how scientists work'

resulting in an outlook on subsequent modelling

Figure 3. A didactical structure for a problem-posing approach to a modelling introduction of an initial particle model.

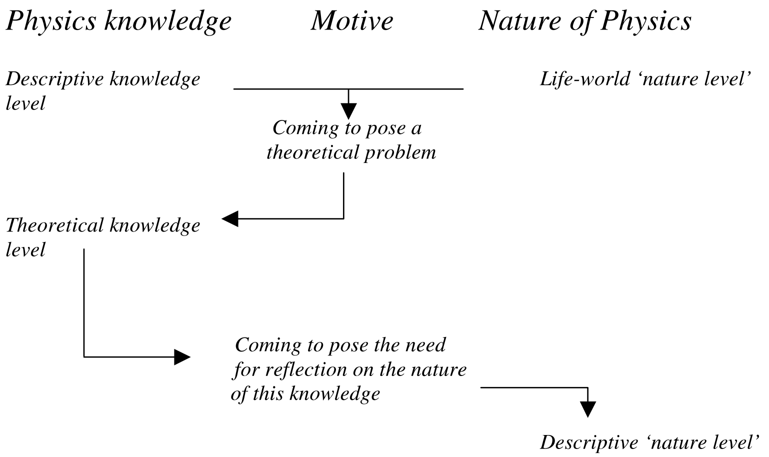


Figure 4. Level structure of a modelling approach to the introduction of a particle model.

motives column, drive each other. The first column deals with the teaching of a particle model and the third with teaching about the nature of physics, in particular about the nature of particle models. This reflects the fact that, in developing this sequence, we aimed at *both* objectives. However, the inter-relatedness of both learning processes was not anticipated in any detail and came out in reflection afterwards. We find this an important outcome as it may represent a natural way in which teaching about the nature of science could be integrated in the teaching of science itself, so that it may not be something like a strange add-on. As such, this can be recognized as an attempt to meet Duschl's (2000) challenge, that was formulated as follows: 'The need for school science programmes to focus on the various public understandings of the nature of science is an important educational goal', for which 'The challenge is to design instructional sequences and learning environment conditions that help pupils become members of epistemic communities'. Figures 3 and 4 show how a didactical structure for such a sequence might look. This aspect comes even clearer to the fore when we compare these structures with the two-column structures of figures 1 and 2. The latter represent only a motives-driven knowledge development, in line with the sequence's single main teaching objective, thereby leaving its epistemological and methodological aspects implicit.

Another aspect that came out in this structure is that ideas about conceptual change theory, or about using analogies, were not applied as such but nevertheless appeared to be present to a large extent in a natural way in our teaching scheme. In fact, in retrospection, this is rather obvious as, in a problem-posing approach, it is tried to evoke and elaborate content-related motives for students to ground the development of their knowledge. This implies that ideas like intelligibility, plausibility and fruitfulness (i.e. the status descriptors in conceptual change; Hewson and Lemberger 2000), come not only self evidently to the fore in the didactical process, but also in a 'natural way' in view of the progress made in the learning of content matter. The same remark applies to a large extent to the concept of 'learning demand' as introduced by Leach and Scott (2002).

In terms of a level structure we may now come to the scheme of figure 4. This level structure was not yet available as an *a priori* instrument in developing our teaching sequence, so this description does not fully apply to the teaching sequence as developed. Moreover, this teaching sequence only gives a first start for the filling of the given levels. In further sequences, this has to be further elaborated and extended. Within this structure, we may again distinguish several didactical phases that, although different in detail, are to a large extent similar to those already formulated (see also later).

The inter-related teaching of subject matter knowledge and general skills

In the structures of figures 3 and 4 both teaching–learning processes are reflectively coupled so that the second evolves more or less at a meta-level with respect to the first. However, nowadays, science education is also expected to contribute to the teaching of general skills that, as such, are not related to any specific science content matter at all. This constitutes another serious didactical problem that asks for further attention. The crux of the problem consists of what it means if one wants to teach skills like 'problem-solving', 'investigating', 'information processing', and so on (Millar and Driver 1987, Taconis et al. 2001). Do they need to be taught at all? And, if so, how can we best do it, and in particular how does this teaching then relate to the teaching of subject matter content? Kortland (2001) has tackled this problem for the 'general skill' of decision-making, which is formulated in our compulsory attainment targets for lower ability students (age 15) as being able to present an argued point of view. Kortland studied decision-making skill in relation to teaching about the environmental waste issue.

This 10-lesson sequence (of 50 minutes per lesson) was set within a practical orientation and dealt with the question of how to deal best with household package waste from an environmental point of view. In a problem-posing approach, this has led to a content-dependent didactical structure as represented in figure 5. After an orientation on personal decision-making about household waste, at the level of using both life-world knowledge and decision-making skills, students come to the recognition that they first need to know more about household package waste. Then, in using this knowledge in having to present their point of view about a decision-making situation, they come to realize that it is not obvious at all what it means to present a 'well argued' point of view. Thus, in reflection, a (still contextualized) number of heuristic rules are made explicit that may help them to structure and check their reasoning. Again, this set of heuristic rules is termed a descriptive level of decision-making, as it describes, organizes and makes explicit the intuitive procedures used so far. Thus, from figure 5, again a content-independent level structure can be abstracted, as given in figure 6.

The first four teaching phases as identified by Kortland (2001) are identical to those already formulated. However, the next two phases are now described as follows:

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

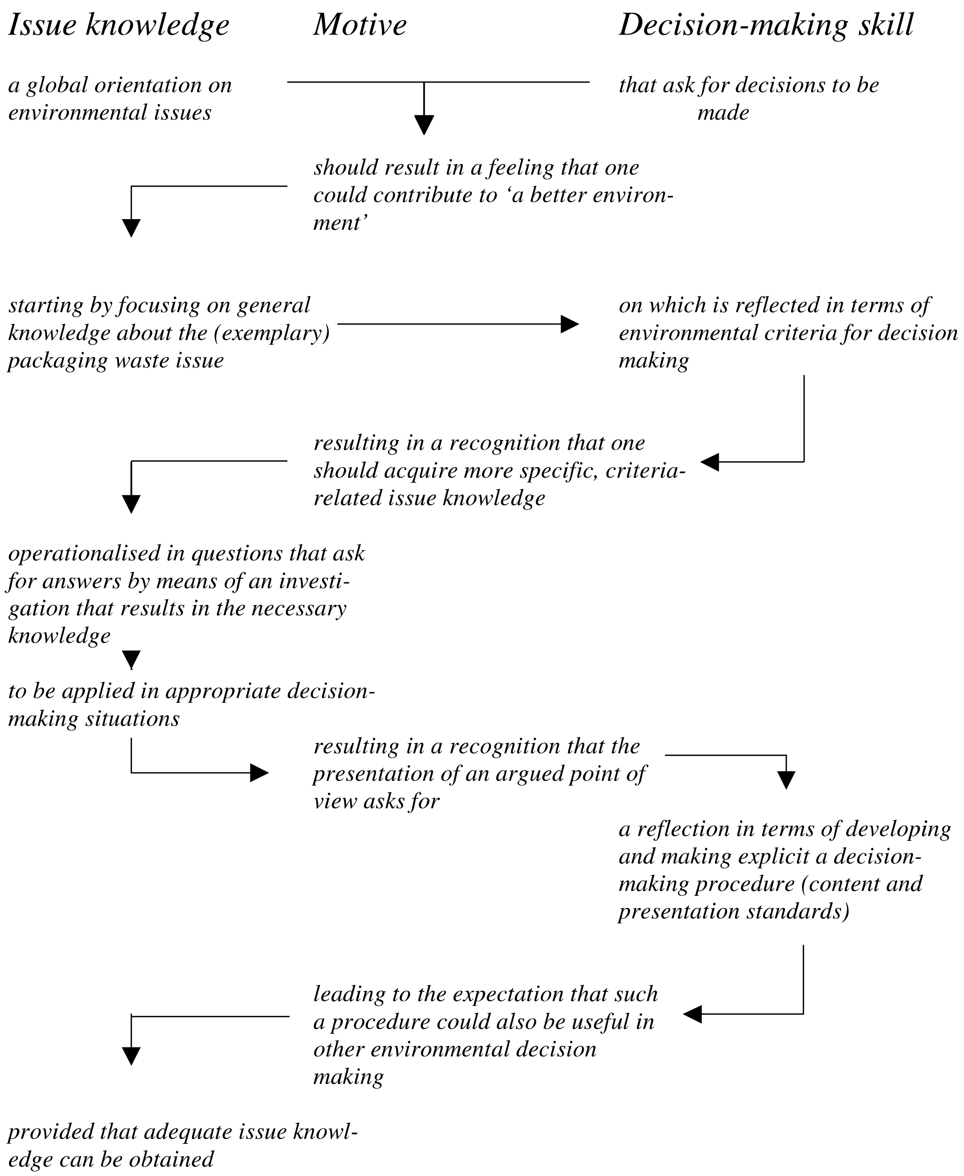


Figure 5. A didactical structure for a problem-posing approach about decision-making on the waste issue.

The structures of figures 5 and 6 consist of three columns, because we deal again with two coupled teaching–learning processes, related to the two main objectives of the sequence. However, the nature and relation of both processes is now quite different from that in the previous case. Both teaching–learning processes start at the everyday level and, by starting from common ground, make productive use of what students already know. As far as the skill of decision-making is concerned, it means that students should not so much learn to make decisions, because they do so all the time, but it seems worthwhile to teach them, in situations for which this

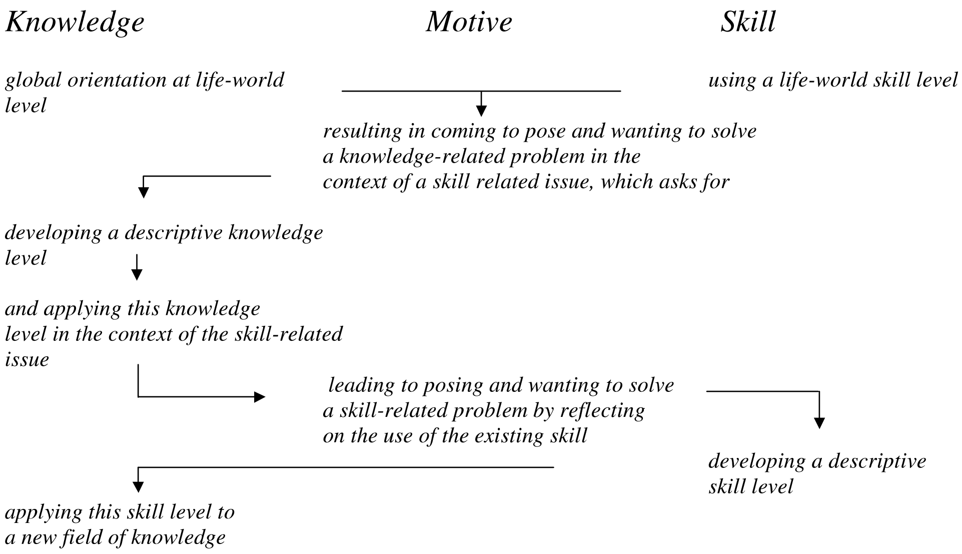


Figure 6. The level-structure of a problem-posing approach to the inter-related teaching–learning of content matter knowledge and a general skill.

seems to be relevant, how to explicitly reflect on the quality of their decision-making procedure. To guide this reflection process, a meta-cognitive heuristic 'tool' may be useful. In the presented structure, this tool is still developed within the context of the waste issue (i.e. within the knowledge context at stake). However, in a series of subsequent decision-making modules, thus as a curriculum strand, this tool may gradually be de-contextualized towards a tool on decision-making itself.

This concludes a brief description of our work on didactical structures so far. Both characteristics, the level structure and the teaching phases, could possibly be interpreted as elements of a more general didactical theory that needs to be worked out further.

Concluding reflection

Now, what may we conclude from the aforementioned? The examples given are meant to represent research-based 'good practices', in which not only results of relevant educational research are taken into account, but also extended and enriched at the level of didactics. As already said in the introduction, in our opinion, it is precisely the filling of that level that is too often skipped in our research, or left as an impossible task for teachers. The given structures, together with their respective scenarios, may not represent the best way of teaching the topics under concern, but, as we would argue, they do represent better ways (in the sense that it is probable that more students will understand and like what is taught in the intended way). And thus they do contribute to making available new didactical knowledge at a level that is in principle applicable for teachers and may help them in solving some of their problems. The structures and scenarios themselves do not describe the necessary learning processes of teachers. However, in our research, these learning processes are documented as well, and could in fact be described in similar structures, representing didactical structures for the learning of content-specific didactics.

The level structures are an attempt to generalize our procedure. In doing so, we focus on characteristics of the knowledge and skills involved, but still within a didactical context. The usefulness of this level of abstraction is, however, certainly a matter of discussion. Nevertheless they may contribute to the development of a more general didactical language and theory that is applicable in more situations (didactical structure, didactical contract, didactical knowledge and/or skill level, didactical phases and didactical functions, purposive orientations, problem-posing approach, etc.) – even though these concepts have not yet been worked out and discussed here in sufficient detail.

In the introduction we mentioned the problem of communicating about the outcome of research on teaching–learning sequences, and in particular about their didactical quality. Now, does the framework described here provide useful opportunities in this respect? In our opinion it does. For example, if results of research on teaching–learning sequences were more reported in terms of underlying didactical structures, on the one hand as operationalizations of explicit basic starting points and on the other as advisable teaching/learning trajectories, a deeper comparison of the didactical pros and cons of the respective approaches could take place. The more so if also more attention would be paid to criteria for didactical quality. Such criteria can in fact be abstracted directly from the considerations already described, such as:

- what is the didactical problem under concern and what is offered as a solution:
  what are the basic views that underpin the didactical structure;
  are those views adequately operationalized; and
  does the resulting structure really make a new and explainable contribution to solving the problem?
- can the designed teaching/learning *process* really be considered as *coherent* from the point of view of the students:
  are the students provided with functioning global and local motives;
  are the students able to construct (guidedly and cooperatively) the expected concepts; and
  do the students reach the intended aims to a sufficient degree?
- is the teaching process sufficiently manageable by the teacher and does he/she succeed in solving unexpected problems in the spirit of the foreseen scenario:
  does the teaching process start from a proper interpretation of common ground;
  do the teaching activities really prepare for and are they really prepared by each other;
- does the teacher provide sufficient construction space for the students and does he/she manage to interact with them productively; and
  is he/she able to monitor the learning process at a meta-cognitive didactical level?

If criteria such as these would get sufficient attention in our communication of research on teaching–learning sequences, we think we could get a clearer view about their didactical quality, which would make it easier to build on them in future research.

Tiberghien (2000) remarks that the design of teaching situations 'for each domain of physics can be an endless task'. Therefore, in her research she focuses on the design of teaching situations that are representative of a set of situations by making use of more general characteristics of physics knowledge. This reflects an important dilemma. We agree that the outcome of didactical research cannot (only) be at the level of teaching situations themselves, although, in the end, the question of quality can only be answered at that level, as each general research outcome that asks to be applied in practice is in danger of not being applied properly. Our way of empirically supported scenarios and 'didactical structures of a certain topic' is another attempt to deal with this dilemma. Of course, such structures, together with their worked out scenarios, cannot succeed without the experience and craftsmanship of good teachers. As such, they are not teacher-proof nor can they guarantee that the learning process of each individual student will be successful. However, they do provide even experienced teachers with new didactical insights that can improve their teaching considerably at key points. That is why they can improve the learning and teaching of a certain topic, in the sense that more students will understand and value, in the intended way, what they have been taught. If more research-based didactical structures (or whatever one wishes to call them) would become available, then from mutual comparisons and discussions more didactical progress would be possible.

Notes

1. The following quotation, as reported by Gunstone (1992), shows that this is not a self-evident condition.

   In the following typical example, the student (P) has been asked by the interviewer (O) about the purpose of the activity they have just completed.

   P: He talked about it . . . That's about all . . .
   O: What have you decided it [the activity] is all about?
   P: I dunno, I never really thought about it. . . just doing it – doing what it says . . . its 8.5 . . . just got to do different numbers and the next one we have to do is this [points in text to 8.6].

   In addition Gunstone (1992) writes: '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 very hard to avoid'. As a remedy, much emphasis has been laid on fostering students' general meta-cognitive knowledge and skills. Students should learn to learn. Without wanting to argue about the value of this emphasis, in our approach we adopt the additional view that it should also be clear to students on content-related grounds why and what they are doing
2. In the development of our scenario we focus on the description of an empirically tested optimal 'average' teaching–learning process. In practice, the actual process will always deviate from the final scenario to a lesser or larger extent. We call it 'good enough', or to have sufficient didactical quality, if the empirical test shows that the anticipated process is feasible for both teacher and students and that the expected learning effects are satisfactorily obtained. This implies that actual unexpected deviations do not essentially disturb the scenario and can be handled adequately by the teacher. It also means that the students in general are able to make the necessary learning steps, so that no lasting conceptual blockades or major misinterpretations result.
3. It should be kept in mind that the structures will be described here only in summary. A full description and empirical justification of each structure is given elsewhere (Klaassen 1995, Kortland 2001, Vollebregt 1998).

4. This means that research in didactics is not only content specific but also, to a certain extent, system specific.

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