5 A problem-posing approach to science education

5.1 Introduction

5.1.1 A crude picture of (the development of) science
In section 4.4.2 it has been argued that "[s]cience can add mightily to our linguistic and conceptual resources, but [that] it can't subtract much" (Davidson, 1985b). The addition consists, on the one hand, in the introduction of specific ways of classifying objects or events, and of relating objects and/or events to one another, and on the other in the recognition of regularities when objects or events are described in terms of these specific ways of classifying and relating. This recognition of regularities may, in the course of an empirical investigation, lead to the formulation of generalizations (inductive hypotheses), e.g.: whales are mammals; whenever a piece of metal is heated it expands. If apart from being confirmed by their instances such generalizations also support counterfactual and subjunctive claims, they may be called lawlike. Someone who knows what their positive instances are and how they cohere with those instances will then have good reason to expect that they will cohere with other instances as well, to project them to unobserved cases and to invoke them to advance counterfactual claims. This does not necessarily imply that they will also be lawlike in the sense of being very precise and exceptionless, although they may provide good reason to believe that there are more precise and more widely applicable generalizations at work and perhaps even point at ways to formulate such improved generalizations. A further addition may then consist in the introduction of ways of classifying and relating with more precise and objective criteria of application, in order to formulate more precise and wider applicable generalizations. The final goal will be generalizations whose positive instances provide good reason to believe that they may be sharpened indefinitely by drawing upon the same ways of classifying and relating in terms of which they are already formulated. It will be clear that this final goal will only be reached, if ever, in fundamental physics.

5.1.2 A few modifications and additions
Of course, the above is just a crude and very simplified picture, so let me make a few

1. This section is inspired by Davidson, 1980a, pp.207-227.
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attempts to paint a somewhat more realistic one (without in any way pretending to be exhaustive). For one thing, the above does not throw any light on the actual development of science. In this respect, Poincaré distinguishes two opposite tendencies in the history of the development of science.

On the one hand, new relations are continually being discovered between objects which seemed destined to remain for ever unconnected; scattered facts cease to be strangers to each other and tend to be marshalled into an imposing synthesis. The march of science is towards unity and simplicity. On the other hand, new phenomena are continually being revealed; it will be long before they can be assigned their place - sometimes it may happen that to find them a place a corner of the edifice must be demolished. In the same way, we are continually perceiving details ever more varied in the phenomena we know, where our crude senses used to be unable to detect any lack of unity. What we thought to be simple becomes complex, and the march of science seems to be towards diversity and complication. Here, then, are two opposing tendencies, each of which seems to triumph in turn. (1952a, p.172-3)

The crude picture may also give the wrong impression that the development of science is a straightforward process. It does not do justice, for instance, to the acts of genius and major breakthroughs that have been involved. Sometimes a specific way of classifying or relating "is so important that with its addition a whole department of science takes on a new look" (Davidson, 1984a, p.183), e.g.: the specific, though simple, way of relating events as 'occurring simultaneously' that Einstein has defined.

The process is also not straightforward in the sense that there may be competing theories, competing ways of describing and/or competing sets of hypotheses. This is quite alright, of course, as long as there is meaningful disagreement between the proponents of competing theories, i.e., as long as they correctly understand each other's ways of describing, know the evidence by which each other's hypotheses are supported, and so on (all of which depends, as argued in chapter 4, on common ground: a shared world, both causally and conceptually, and shared norms of rationality). They can then challenge each other and, e.g., think of experiments in which the different theories lead to different predictions, and so on.

Furthermore, the development of science has not always proceeded without difficulties. It has not always been and is not always the case, for instance, that the proponents of competing theories reach a meaningful disagreement, but instead experience sheer unsurmountable difficulties in their attempts to understand one another, even to the extent of giving up such attempts altogether. It then almost seems as if they "practice their trades in different worlds" (Kuhn, 1970a, p.150). In this connection, Kuhn has introduced the notion of 'incommensurability': "In the transition from one theory to the next words change their meanings or conditions of applicability in subtle ways. Though most of the same signs are used before and after a revolution - e.g. force, mass, element, compound, cell - the way in which some of them attach to nature has somehow changed. Successive theories are thus, we say, incommensurable" (1970b). Now, of course, these changes of meaning are in principle harmless: they are not intractable and correct interpretation will identify them as such. In practice, however, the subtle changes of meaning with respect to
some words may easily give rise to situations in which two scientists fail to recognize that they do not use those words in the same way, and as a result think they disagree on issues. In the terms of section 2.2 it can be said that they then do not properly solve the problem of interpretation: by wrongly assuming identity of meaning they come to attribute beliefs to the other that the other does not, in fact, hold, and thus come to misunderstand each other's theory. Ramberg therefore suggests to not so much think of incommensurability as a relation between theories, world views, social practices or paradigms, but rather as "a characteristic of the discourse that results when we proceed as if we are using the same vocabulary, and so interpret others by applying linguistic conventions to which they are not party" (1989, p.132). In any case, the communication breakdowns between proponents of successive or competing theories must be characterized as communicative failures. Whereas the 'communicators' involved may come to think of each other as "living in different worlds, [they may in fact], like those who need Webster's dictionary, be only words apart" (Davidson, 1984a, p.189).

As any human enterprise, finally, the scientific enterprise is of course also subject to all sorts of human failings. Apart from the above mentioned communicative failures, one may also think of errors in calculation and, more seriously, acceptance of doctrines on inadequate evidence, neglect of ethical issues, fraud, obsession with power, blindly following authorities, and so on.

5.1.3 Science education
The picture of (the development of) science that has been presented in section 5.1.1 gives rise to the following picture of science learning: it is a process in which pupils, by drawing on their existing conceptual resources, experiential base and belief system, come to add to those (by arriving at new ways of classifying and relating, studying events that never before they have witnessed or paid attention to, framing new inductive hypotheses, and so on), in order to further and further characterize and explain more and more aspects of the natural world. Just as in section 5.1.2 I have briefly indicated that the former picture is far too crude and simplified, I will in the remainder of this chapter illustrate and argue, in somewhat more detail, that a process of science learning too, if it is to make sense to pupils, involves much more than painted in the latter picture.

Many of the expressions that correspond to the scientific terms that are to be introduced, for instance, are also used in ordinary language, and very often in a way that differs from the way they are going to be used in the scientific theory. The introduction of scientific terms may thus involve changes of meaning with respect to some expressions.

Moreover, if pupils are to meaningfully engage in an activity there should be a sense in which they know why they are going to do it. They will have to develop some sense of purpose for going to study events they have never witnessed or paid attention to; the inductive hypotheses should become reasonable for them; an intention to improve on already established generalizations should come forward, etc. Furthermore, if the process of science learning is to take place at all, in the minimum sense that pupils are prepared to learn about some scientific topic, they should at least take sufficient interest in it and be sufficiently motivated to participate in a serious way. In short, pupils' process of science learning, if it is to make sense to them, not only involves additions to their beliefs
and conceptual resources, with accompanying changes of meaning, but also, and irreducibly related to these, *evaluative attitudes* (desires, aims, interests, etc) and changes therein, both on a global and local level.

In sections 5.2 and 5.3 I try to illustrate that the two aspects just mentioned, the introduction of scientific terms as part of pupils' entrance into some scientific theory and providing pupils with a sense of purpose and direction respectively, are often neglected, or insufficiently or inadequately taken into account in science education. I also try to illustrate that science education is not likely to contribute, and may instead even damage, a process of insightful science learning if the two aspects are neglected or inappropriately taken into account.

In section 5.4 I sketch an approach to science education that explicitly takes these aspects into account, and whose point is, more generally, to make pupils *want* to add to their conceptual resources, experiential base and belief system, in a way that leads to their understanding of science. I do not propose this approach, which I call *problem-posing,* as a general theory of teaching and learning. I rather propose it as a programmatic view of the possibilities for improving science educational practice at a content-specific level, which are to be further explored and empirically realized by science educational research. The results of this research will then be what in section 5.4 I call *didactical structures,* roughly: examples of good science education.

### 5.2 The introduction of scientific terms, as part of pupils' entrance into some scientific theory

This section can be read as a continuation of section 2.2 in the sense that it further elaborates the educational consequences of the, what I consider to be, trivial point that many expressions that correspond to scientific terms are also used in ordinary language, and very often in a way that differs from the way they are used in the scientific theory that pupils are supposed to learn. It is also a continuation in the sense that I will illustrate these consequences at the (different) ways in which expressions containing the word 'force' are used in mechanics and in pupils' intuitive theory of motion (cf section 2.2.3). I hope it will become clear that the lessons which can be drawn from this particular case carry over to other cases as well.

#### 5.2.1 Linking up with pupils' existing knowledge includes linking up with their existing uses of language

In section 2.2.3 I have summarized an intuitive theory of motion that is formulated in

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2. I have chosen this name for two reasons. First, because it is part of a problem-posing approach to bring pupils in such a position that they themselves come to pose the main problems they are going to work on. Secondly, I intend problem-posing to be understood as sort of opposite to problem-solving, which in my opinion receives much to much attention, both in science education itself and in research on science education.
terms of expressions containing the word 'force' and that, thus formulated, pupils hold true. I have also noted that on the face of it (more precisely, if identity of meaning is assumed with respect to those expressions), pupils' intuitive theory is in flat contradiction with Newton's laws. However, by drawing attention to the interdependence of belief and meaning (cf section 2.2.1), I have observed that the fact that pupils hold true the intuitive theory as formulated does not yet throw any light on what it is that they believe. The problem of interpretation is that it still needs to be found out which beliefs are represented by their holding true the intuitive theory. What I have subsequently done in order to solve this problem, is to take note of the circumstances under which they hold true (fragments of) their intuitive theory, and to assign such meanings to their expressions containing the word 'force' that, thus reformulated, their intuitive theory translates into a correct pattern of beliefs. In chapter 4, moreover, I have argued that it is simply part of what it is to have beliefs at all, that correct interpretation necessarily requires us to so assign meanings to the words of others that by and large their sentences are true (according to us) under the circumstances that they hold those true. In doing so, I have also made explicit that pupils' uses of expressions containing the word 'force' cannot be interpreted in accordance with scientific usage. Their use of the expression 'to exert a force on,' for example, is such that they use it in sentences of the form 'A exerted a force on O,' where A is an agent and O an object, and hold those sentences true just in case (1) there was an action of which A was the agent, and (2) something happened to O, and (3) A's action caused what happened to O.

Let me now reverse the above line of reasoning to simply point out that it must be part of their learning mechanics that they learn to use and understand, e.g., the expression 'to exert a force on' differently from how they use and understand it before education. For if Newton's laws are understood in accordance with their pre-instructional usage, those laws are on the face of it in contradiction with the plainly correct beliefs that are represented by their holding true their intuitive theory.

5.2.2 Without linking up with pupils' existing uses of language it is unlikely that they arrive at a proper understanding of science

It is a striking feature of common courses in mechanics that they do not take into account the above simple observation that it must be part of pupils' learning mechanics that they learn to use and understand, e.g., the expression 'to exert a force on' differently. It is not only the case that no attempt is made to indicate how this expression is used in mechanics (and why it is thus used), but it is not even indicated that in mechanics the expression is (going to be) used differently. What comes closest is that after a presentation of Newton's first law it is usually remarked that this law seems to be in contradiction with the fact that in normal circumstances moving objects come to a stop when left on their own, but that the contradiction is only apparent because closer inspection of the circumstances reveals the presence of retarding frictional forces.

So it is pretty much up to pupils themselves to figure out, on the basis of how Newton's laws are applied in various situations by the textbook and the teacher, both how to describe situations in terms of expressions like 'to exert a force on' and, given an
appropriate such description of a situation, how to subsequently apply Newton's laws to it. After some training, pupils usually acquire some ability to perform the latter step. In particular, given the forces that are exerted in a given situation, pupils are often able (apart from mathematical difficulties) to apply Newton's second law in order to calculate, e.g., the braking distance of a car. At the same time, however, many pupils (and even university students, including myself as it turned out during teacher training) are often not able to perform the first step: given relatively simple (but non-standard) situations, they are often unable to describe those correctly (i.e., in accordance with scientific usage) in terms of expressions like 'to exert a force on' (see, e.g.: Warren, 1971; Viennot, 1979; Clement, 1982; McCloskey, 1983). They do not describe situations in terms of pairs of objects that exert mutually opposed forces on each other; in the situation of a car or a bicycle travelling on a flat road they identify a balance between the 'driving force of the engine' or the 'force of the cyclist' and the resistance of the air and the road; as they used to do before instruction, they describe situations in terms of expressions like 'to have a force' and 'to get a force from,' and so on. In short, also after instruction much of their talk is to be best understood as in section 2.2.3, i.e., as in line with the intuitive theory of motion.

I think the above represents the sort of hybrid between the intuitive theory of motion and Newtonian mechanics that many pupils arrive at after common courses in mechanics, and I agree with the researchers who have established it that this is an unsatisfactory outcome. But as already noted in section 2.2.3 I do not agree with the researchers who seek the source of this outcome in the failure of those common courses to address pupils' intuitive theory in order to overcome it. It need not be overcome simply because, if appropriately interpreted, it is correct.

My own analysis of the source (or at least one of the basic sources) of this outcome is based on the observation that correctly applying Newton's laws cannot be separated from a specific way of describing situations (such that they are amenable to Newton's laws). According to me, the failure of common courses in mechanics is that they neglect this 'specific way of describing' part. As a consequence, it is more or less up to the pupils themselves to fill in this part, and I think it is not surprising that this is to demand too much of many of them. But then, not being provided with additional conceptual resources, it is also not surprising that after instruction many of them only use the conceptual apparatus that they already commanded before instruction in describing (non-standard) situations.

5.2.3 Incommensurable discourse

3. Note that this observation corresponds, more generally, to what has been argued in section 4.4.2, namely that explanations by means of laws are sensitive to how the events, situations or states to which they are to be applied are described. The reason is that laws deal, not with particular events, situations or states, but with properties of such. Therefore, events, situations or states only instantiate a law, and hence can only be explained in the light of a law, in as far as they have the relevant properties (the properties with which the law in question deals).
In common courses in mechanics (as in science education more generally), there is an emphasis on quantitative exercises concerning standard and pre-fabricated situations, and I have already noted that in this area pupils usually make some progress. This one-sided emphasis may, on the one hand, further account for the fact that many pupils make little conceptual progress (cf. Warren, 1979) and, on the other, explain why during those courses themselves this limited progress does not surface very often and only comes forward by research that explicitly explores conceptual progress.

The below fragment of a lesson in mechanics, however, does present an example in which, I think, the above mentioned failure of common courses in mechanics does come forward. In the lesson preceding the one from which the below fragment is taken, the pupils watched a specially developed video, which is about the forces that are acting while riding a bike. The below transcript begins with the teacher, who intends to summarize and elaborate on the video by means of the well-known air track. His introductory question, in which he asks for the forces acting on the glider when it rests on the not yet operating track, is meant to simply remind the pupils of the supposedly well-known static forces that are acting in that situation. Then the following discussion occurred, which took about twenty minutes.

1 Teacher: The video has been about forces that act when cycling. Well, here [points to the glider on the track] I have a kind of bicycle. Let me now first ask what forces are acting on it. Just try: what forces do you think are acting at this moment; are there any forces acting?

2 Eric: Gravity.

3 Teacher: Gravity, Eric says. What if gravity were the only force, what would happen then?

4 Eric: Then it would go down.

5 Teacher: Then it would go down. Ernie, what other forces could be acting?

6 Ernie: Eh ... well ...

7 Teacher: What prevents it from falling down?

8 Ernie: The track.

9 Teacher: Right, the track. So the track has to supply a counterforce to prevent the glider from falling down. Just for the sake of completeness: Eric, which direction has gravity?

10 ?: [joking] Upwards.

11 Eric: No, downwards.

12 Teacher: So, Orson, the force of the track is upwards. Right?

13 Jane: How's that?!

14 Orson: Well, otherwise it would fall down.

15 Teacher: Otherwise it would fall down, he says. So: if it did not rest on the track and I dropped it, then only gravity would act and it would fall down. If the track wants to stop it, then it will have to push the glider upwards.

16 Jane: But the track does not push, does it?

17 Teacher: The track does not push.

18 Jane: No...

19 Orson: Well, the track is just there.

20 Jane: ...it's just there.
[Some pupils are mumbling things like: 'Don't make such a fuss. Just accept it.]

Teacher: If you drop it, it will fall down, a force will act upon it.

Jane: Sure, if the track is not there.

Teacher: Okay. If you put it on your fingers... I can't take it off. [The teacher cannot get the glider off the track, and takes a small weight instead.] It's the same with this thing [the weight], isn't it. If you drop it, it will fall down. Now I want to stop it [places the weight on the tips of his fingers]. Since it is such a small weight, you don't feel much. But if you put a heavy weight on your fingers, you will feel it.

Jane: Okay.

Teacher: That is because you will have to exert a counterpressure. So you do have to...

Jane: Sure, if you're doing that yourself.

Teacher: If I place a heavy weight here, then my fingers will go down. If I want to keep it in place, I will have to push it upwards. The track will do that too, it's just that we don't notice that. We don't notice that the track does it, the track doesn't move...

Carl: Yes, but the track can't push upwards, can it?

Teacher: ... but the track in fact does it as well.

Carl: Yes, but the track can't do that, can it?

Teacher: Oh yes, it can do just that.

Carl: You can push upwards with your fingers, but the track can't.

Teacher: Let me take something else, something more flexible than metal. [fetches a piece of foam rubber and puts it in front of him] Here goes. So I will now try to convince you that the track really exerts an upward force. That is, I did agree with Orson, Jane did not, let's see whether we can come to an agreement. [puts the small weight on the foam rubber, which gets pushed in a bit] If I put this thing here, the foam rubber gets pushed in, doesn't it? Well, actually I need something a bit heavier...

Jane: Oh, well I do believe you as it is.

Teacher: Do you? So you do actually believe that. [laughter] So: the foam rubber will get pushed in, if you put something heavy on it. And if we don't put something heavy on it, but push it in and let go [does so with a finger], what will happen then?

Jane: Then it will come up again.

Teacher: Then it will come up again. Why's that?

Jane: Well, because there's nothing on it.

Teacher: Sure, but what does it do then, when it comes up? Then it pushes upward, doesn't it?

Jane: What?

Teacher: [somewhat more pressing] Then it pushes upward, doesn't it?

Jane: No, then it just gets back to its original state.

[Some pupils seem to suggest that Jane is just being stubborn.]

Jane: No, I don't think that has got anything to do with it.

Teacher: Don't you? I push the foam rubber in, put something on it, and the foam
rubber pushes it upwards. Then that is an upward force.

Teacher: Do you?

Jane: Yes. That is not ... well ... no, that is not a force. I don't think it really is a force.

Teacher: If you want to push something up, then for that purpose you will have to exert a force. And now: [pushes the weight into the foam rubber and then lets the foam rubber spring back] it is pushed in and it pushes the weight back up.

Jane: Okay.

Teacher: But you don't think that's a force.

Jane: Right.

Teacher: You don't think that's a force. For it is the same, isn't it? And do you consider this to be a force, when it falls down?

Jane: Sure, that's gravity.

Teacher: So: the downward motion is due to a force, but if it moves up [lets the weight again move up from the foam rubber] then that is not due to a force?

Jane: Right.

Teacher: What if I now ... I throw it upwards, like this.

[Jane also begins to laugh about the awkwardness of the whole situation.]

Teacher: Is that a force or not?

Jane: [laughing] It is, of your hand it is.

Teacher: Of my hand it is. And now I let the foam rubber do it [again does so] and then it is no longer a force.

Jane: [still a bit laughing] Right.

Teacher: What, then, is the difference?


Teacher: So because it goes all by itself, that is why according to you it is no force. If it now of itself gives a slap, then that will be a force.

Jane: Yes.

Teacher: I see. Well, so it seems that we haven't been making much progress. I do think there will be a force if you push it in, and Jane still doesn't think that that is a force. I'll leave it at that for a while. For the time being, everybody may think about it as he wishes. I would like to know, however, what the others do think about it.

[Of the others, most indicate that they agree with the teacher, while no one indicates to agree with Jane. Some pupils, among which Orson and Carl, are in doubt.]

Teacher: Alright. Let's leave it at that for now. Perhaps I will be able to convince you at a later time. According to me, the difference between the foam rubber and the metal is that it can't be noticed that well that the metal is springy. But also the metal has got some spring that allows it to push back. So the metal is harder and -but now I speak for myself- it gets pushed in, but it does spring back and
thus exerts a counterforce. Okay. It is sort of funny, though, that we still don't agree.

Let me give an analysis of this transcript. A first thing to note is that the teacher analyzes his discourse with Jane as their having a *difference of opinion* about whether "the track really exerts an upward force" (34, 69). Accordingly, he sees it as his aim to convince Jane that his opinion is the correct one (34, 71). He does so, not by arguing in terms of Newton's laws as he probably quite rightly assumes this to be inappropriate at this stage, but by more or less ostensively and comparatively pointing at ever more clearly visible cases of 'acting forces.' In the end, the teacher considers his attempt a failure: "I do think there will be a force if you push it in, and Jane *still* doesn't think that that is a force" (69).

Given that this is how he evaluates the situation and that he probably cannot think of any other way to convince Jane, it is a fair thing of him to explicitly state that, for the time being, he will let the matter rest (69). He even emphasizes: "It is sort of funny, though, that we still don't agree" (71).

But is the teacher right in analyzing his discourse with Jane as their having a difference of opinion? I do not think so. Of course Jane agrees that the glider's being supported by the track is similar to the weight's being supported by the teacher's fingertips in the sense that in both cases an object's falling down is prevented. Of course Jane agrees that throwing a weight upwards and letting the foam rubber do it are similar in the sense that in both cases the weight is made to move upwards. And of course the teacher agrees that the piece of foam rubber and the metal track cannot of themselves push something upwards or give a slap in the way that we can (16, 29, 33, 67-68), and that the foam rubber springs back without us having to do anything, that it goes all by itself (66). And without doubt Jane could also come to agree with the teacher (perhaps along the lines suggested by Minstrell, 1982) that the metal track is like the piece of foam rubber in the sense that it is sort of springy too, but unlike metal in the sense that metal is harder and that its springiness cannot be observed that well (28, 71).

So the teacher and Jane actually *agree* on all the similarities and dissimilarities between the various situations. Moreover, towards the end of their discourse the teacher is sort of able to predict when Jane will say that a force is exerted and when not (56, 63, 67). Nevertheless, they have an ongoing and unresolved quarrel. If they were asked the question 'Does the track exert an upward force?,' or 'Does the foam rubber exert an upward force?,' the teacher would answer 'Yes' and Jane would answer 'No' (34, 71).

According to me their discourse runs aground in this yes-no stalemate, not because they really have a difference of opinion, but simply because they do not in fact answer the same question -more particularly, because they do not assign the same meaning to the expression 'to exert a force on.' In other words, their discourse is incommensurable (cf section 5.1.2). The teacher uses the expression in accordance with scientific usage. Jane, on the other hand, uses it more or less as indicated in section 2.2.3. More precisely, I think her use of the expression is to be interpreted as follows. She uses it in sentences of the form 'A exerted a force on O,' where A is an agent and O an object; she holds those sentences true in case there was an action of which A was the agent, and something happened to O, and A's action caused what happened to O, or in case A supports O
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(prevents that it falls down). Again, I think this interpretation is correct simply because, thus interpreted, whenever she answers 'Yes' (or 'No') to the question 'Does this exert a force on that?' she is, according to me, right in doing so. I agree with her, for instance, that when the glider rests on the track, an utterance of her sentence 'The track exerts a force on the glider' is not true, simply because the track is not an agent. It could not, of itself, cause something to happen to the glider, e.g., throw it upwards. Moreover, by asserting her sentence 'The foam rubber does not exert a force on the weight,' she is not denying that the weight moves upwards nor that the foam rubber has been involved in the weight's upward motion, but only, and rightly so, that the foam rubber, of itself, has caused the weight's upward motion. It is rather the teacher who, by pushing the weight deeply into the foam rubber and then letting the foam rubber get back to its original state (43), in effect has caused the weight's upward motion. So I conjecture that Jane would have answered 'Yes' if concerning this situation she was asked 'Does the teacher exert a force on the weight?' In terms of the intuitive theory of motion it might be said that the teacher hands over his force to the weight via the foam rubber."

On my analysis, the conflict that the teacher and Jane themselves think they are having (34, 69) is just an apparent one, and their discourse a communicative failure. The source of the miscommunication relates, I think, to the fact that common courses in mechanics simply neglect the 'specific way of describing' part: Jane has not picked up that in mechanics the expression 'to exert a force on' is used in a way that differs from ordinary usage; the teacher does not even seem to consider the possibility that Jane might use the expression in a way that differs from scientific usage. So if the failure of common courses of mechanics surfaces in those courses themselves, it is likely to manifest itself in the form of incommensurable discourse. The result then is that teacher and pupils will feel a gap between them or, as ten Voorde (1990) calls it, a gulf of ununderstandableness, without being able to bridge it. In the above example the teacher may have felt the gulf as his being unable (despite all his efforts) to convince Jane. Jane may have felt it by the teacher's tireless attempts to convince her of something she just cannot believe: "I really

4. I refer to Klaassen & Lijnse (in press) for a more elaborate comparison between my interpretation and one that others might give. I suppose, for instance, that Clement would attribute to Jane the, as he calls it, 'deep seated' alternative conception of 'static objects as barriers that cannot exert forces' (1993). If this supposition was correct, Clement would not sufficiently disentangle the notions of belief and meaning. That is, whereas he would, I guess, admit that pupils do not use and understand expressions containing the word 'force' as a scientist does, in his formulation of what Jane believes he nevertheless would use such expressions: Jane believes that static objects are barriers that cannot exert forces. He could thus in some sense be said to be aware of the problem of interpretation, i.e., that an identification of what Jane believes cannot be separated from an identification of the meanings she assigns to the expressions she uses to state her beliefs, but he could not be said to have solved it. For the statement 'Jane believes that static objects are barriers that cannot exert forces' is not informative as long as it is not specified what Jane means by her expression 'to exert a force on.' Furthermore, whereas Clement would aim to make Jane "overcome the dominance of an alternative conception" (ibid), on my interpretation there is no need to aim at that simply because Jane's beliefs are quite alright. I do see a need, however, to make explicit and plausible a new way of using the expression 'to exert a force on.'
do think that's strange" (47; 66).

5.2.4 Creating appropriate places in pupils' existing conceptual apparatus

If Jane and her teacher had realized that their discourse was incommensurable, they would also have been able to find a way out of it: "what the participants in a communication breakdown can do is recognize each other as members of different language-communities and then become translators" (Kuhn, 1970a, p.202), instead of remaining vain convincers. The teacher might e.g. have proposed something like this: to use the expression 'to exert a force on' in sentences of the form 'O₁ exerts a force on O₂,' where O₁ and O₂ are objects and, in particular, O₁ need not necessarily be an agent; to assent to a sentence of that form just in case something happens to O₁ (or, is prevented to happen) that would not have happened (or, would have happened) if O₁ had not been there. All parties would then have assented to 'The track exerts a force on the glider,' if only because, if the track had not been there, the glider would have fallen down. All parties might eventually also have assented to 'The glider exerts a force on the track,' after it had been established that the track does get a bit deformed when the glider is placed on it. Along the same lines it might be established that then also the glider gets a bit deformed, perhaps via appropriate intermediate situations, e.g.: if one pushes down a spring with one's hand, the hand is pushed in a bit as well. The above proposal might accordingly be modified by deleting the parts between parentheses. All parties would then still assent to 'The track exerts a force on the glider.' Moreover, from the way this modification has come forward, they might even begin to wonder whether there are in fact situations in which they would assent to 'O₁ exerts a force on O₂' but dissent from 'O₂ exerts a force on O₁.'

Let me try to draw some lessons. Note, first of all, that I have only brought forward the above proposals in order to illustrate that Jane and her teacher might have got out of their incommensurable discourse. I have not meant to suggest that the proposals are useful intermediate steps if one aims to devise a course in mechanics in which pupils do arrive at a proper understanding. What I do want to suggest, however, is that in such a course it will at least be necessary, in order to prevent incommensurable discourse, to make explicit agreements concerning the way that, e.g., the expression 'to exert a force on' is going to be used. What I would also like to suggest is that this will be necessary but not yet sufficient. For suppose that the last proposal above is indeed useful in the light of a further development towards Newtonian mechanics, and that it is indeed explicitly brought forward that the expression 'to exert a force on' is going to be used thus. What is still lacking then, is that pupils need not yet appreciate why they should thus use the expression, i.e., what the point is of having available a relation that holds between two objects whenever something happens to the one object that would not have happened if the other had not been there.

In my opinion this poses an important educational task, and not just in the case of mechanics. It concerns, more generally, the introduction of scientific terms in a for pupils meaningful way, as part of their entrance into some scientific theory, namely: to induce in pupils a need or, at least, good reasons for having available the terms that one intends
to introduce. This need or these good reasons are to create, so to say, a place in pupils' conceptual apparatus for the term to be introduced to occupy. I also think that in general this task is non-trivial, because generally pupils' reasons, or need, for having available a particular term cannot, at the stage that it is to be introduced, coincide with what may be called the teacher's or curriculum deviser's reason to introduce it, namely that having available such a term is useful in the light of a further development towards a scientific theory. For the case of mechanics, I have not yet given this important task enough thought and therefore I now refrain from making any suggestions. I refer to chapters 6, 8 and 11 for some suggestions concerning cases that I have given some thought.

5.3 Providing pupils with a sense of purpose and direction

This section concerns the evaluative attitudes that, as I have already indicated in section 5.1.3, ought to be explicitly taken into account in science education (along with the cognitive attitudes, of course). The evaluative attitudes that I have in mind here not so much concern pupils' perception of the affective climate of the learning environment (cf Créton & Wubbels, 1984; Wubbels & Levy, 1993b; see also section 10.2), but rather pupils' perception of their learning process with respect to content. This is not to say, of course, that I consider the former unimportant or independent of the latter, but simply that my focus of attention is on the latter, if only because I think that the latter receive far too little attention in (research on) science education.

As a consequence I do not focus on interpersonal teacher behaviour that is appropriate in order to create and maintain a classroom atmosphere that pupils appreciate as positive, but on content-oriented ways of planning and guiding that are appropriate in order to create and maintain a learning process that pupils appreciate as an internally coherent one with a certain direction, and in whose development with respect to content they take an active interest. Or rather, in this section I focus on ways of planning and guiding that are not particularly appropriate in this respect. It is perhaps good to note at the outset that by criticizing these ways of planning and guiding I do not intend to offend anyone, but to make a plea for explicitly taking into account the content-directed evaluative attitudes in planning and guiding science education, and to show that appropriately doing so poses a non-trivial educational task.

5.3.1 Traditional science education

With varying degrees of emphasis, I think the traditional setting in which much science education takes place is as follows. There is a textbook whose main line is a story in which the authors present, explain and illustrate the theory. The pupils are to read (study) this story, often as homework, and during lessons the teacher tells the story in his or her own words and answers pupils' questions about it. In the textbook the story is regularly interrupted by suggestions for experiments, which usually are to further illustrate the

5. Note that this task is also relevant if the introduction of the scientific term does not involve a change of meaning, i.e., if there is no ordinary use of the expression corresponding to the term.
theory, and by exercises with various degrees of difficulty, by means of which pupils are
to digest the theory. The experiments are carried out by the teacher or, if they are not too
difficult and time-consuming, by the pupils (often in small groups). The teacher selects
the exercises that the pupils are to make, usually as homework. Later on (e.g., in the next
lesson), the teacher makes clear what the right answers to the exercises are, e.g., by
showing (or letting pupils show) how to arrive at those answers, or by pointing out what
pupils who have arrived at the wrong answer have done wrong (or by letting other pupils
point that out). At regular times, finally, there are tests, in which pupils are to solve some
problems that (mostly) do not deviate much from the earlier exercises.

Below I somewhat further elaborate this traditional setting, in order to indicate that it
does not seem very suited to actively involve pupils in the development of their learning
process with respect to content.

Following a rational reconstruction
The pupils are hardly challenged to play an active role in the establishment of the theory.
They rather are expected to (be able to) follow the story in which the authors present,
explain and illustrate the theory, by reading the textbook and listening to the teacher. The
story itself, moreover, is often of a kind that does not really stimulate pupils to take an
active interest in following it. For it is often cast in the form of, what may be called, a
rational reconstruction. That is, the content is sequenced in a way in which someone who
has already mastered the knowledge may, in hindsight, conveniently reconstruct or
summarize it, or build it up from first principles. In chapter 3 I have, in this respect,
pointed at the common practice of basing a treatment of the topic of radioactivity upon
micro-level explanations. One may also think of the common practice to almost
immediately present Newton's laws in introductory courses in mechanics, to quite early
introduce molecules in chemistry courses, and so on. The story is thus not really written
from where pupils are, but rather from where they should end. Moreover, for someone
who has not already mastered the knowledge, the point of earlier parts of the story can, at
best, only come forward in hindsight, in later parts of the story (or by making the
exercises).

Explaining from above
I think it is also quite common in a traditional setting that in their explanations teachers
do not really involve pupils. For although teachers usually do their utmost to make
themselves understood, they often do not involve pupils in the process of making
themselves understood or in finding out whether they have made themselves understood
as intended (and thus fail to do what, as argued in chapter 4, is an essential ingredient of
mutual understanding). Of course, teachers do ask questions in order to check whether
they have been understood, but then this check usually consists in checking whether a
pupil gives the correct answer, i.e., the answer they themselves would give. If not,
teachers often do not try to understand the pupil's answer (e.g., what exactly it is that the
pupil answers, and why) but make sure that the correct answer comes forward, perhaps by
asking another pupil and still another until eventually the correct answer is given, or else
by giving the correct answer themselves. And if a pupil asks a question, teachers often do
not make a real effort to understand that question (what exactly it is that the pupil asks, and why), but simply give the correct answer to the question as they understand it. The below fragment is an example of the latter. It is taken from a lesson in a middle ability class that used the unit *Radiation, you cannot avoid it...* (cf. chapter 3). The lesson was about chapter 4 of that unit (cf. figure 3.1). Earlier in the lesson the teacher had shown a Geiger counter to the pupils and had held it close to a jar containing some radioactive stones.

1 Sandy: But Sir, I've seen a film [probably Silkwood] and that was in a nuclear power station...
2 Teacher: Yes.
3 Sandy: ...and somebody there was contaminated. Then they are cleaned with a steel brush. But it will have gone inside, won't it?
4 Teacher: Yes, but were they ...? Then some radioactive substance had come on them.
5 Sandy: And then you heard a bell ring when you passed underneath.
6 Teacher: Right.
7 Sandy: They wore a suit and things like that...
8 Teacher: Yes.
9 Sandy: ...but it will have gone through, won't it? And still they are...
10 Hank: Well, you had to hold your hands in this way on that thing.
11 Sandy: Yes.
12 Teacher: Well, perhaps it will be on the suit, won't it.
13 Sandy: Yes, but you had to hold your hands before it, didn't you.
14 Hank: When you've got too much of it on your hands, it will ring
15 Sandy: So that's what they had ... when you've got that, it will ring very loudly.
16 Teacher: Yes. Well, you could ... Look, suppose an accident happens in that power station, Sandy. Or you do something wrong, take hold of radioactive substances or something. Of course you can take hold of a stone like that [points to the radioactive stones in the jar] and then there will always come some small bits on your skin and on your clothes ... always. And when you then walk underneath or past a Geiger counter, you will hear it tick. Well, that's roughly how the system works.
17 Sandy: Never mind.
18 Teacher: [somewhat surprised] Yes. Well, that is indeed ... that is a safety measure.

Note, first of all, that by building on the information that the pupils provide (some people were contaminated, 3; a bell rang when they passed underneath, 5, or held their hands before it, 13-15), the teacher gives a correct explanation of the situation: some radioactive substance had come on them (4) or on their suits (12); perhaps because they had accidentally taken hold of some radioactive material, just like if we took hold of one of those radioactive stones, some small bits would come on our skin or clothes (16); what they passed underneath or held their hands before, was a Geiger counter (16); the Geiger counter would tick if we, with small bits of one of the radioactive stones on our skin or clothes, walked past it (16). Thereby the teacher has also answered what he takes to be Sandy's question: what the point is of brushing contaminated people.
Nevertheless, Sandy does not accept the teacher's explanation and, in the end, withdraws: Never mind (17). The reason is, I think, that in her opinion the teacher has not answered her question. For her question is what the point of brushing is when it has already gone inside (3, 9). 'It' here probably refers to what in section 2.5 I have called radiation*: the highly penetrative instrument that, as long as it is inside an object, causes damage to that object. So by talking about radioactive stones and Geiger counters (16), she may have felt that the teacher is simply parrying her question. We know, of course, why the teacher is talking about radioactive objects and Geiger counters. For the teacher and we know that a Geiger counter does not tick near a person that has been close to, but has not touched, a radioactive object: one does not get contaminated by irradiation. Sandy probably does not know this, and most likely uses the expression 'is contaminated' as indicated in section 2.5: as applying to objects that have received radiation* (and therefore may do damage to their surroundings). So when she now hears that the apparatus underneath which the nuclear workers had to walk or before which they had to hold their hands is a Geiger counter, just like the one she has seen earlier in the lesson, for her (unlike for the teacher and us) this does not imply that the nuclear workers who caused the bell to ring must have carried radioactive material on them. After the teacher's explanation, therefore, her question still stands.

As in the fragment discussed in section 5.2.3, we may say that here too there is a gulf of ununderstandableness. Sandy's withdrawal may show that she has felt the gulf. The teacher's surprise after Sandy's withdrawal may show that he has felt it too: he may feel he has given a clear explanation (as indeed he has for those who know enough), and still Sandy does not seem to understand.

I think that the phenomenon of explaining from above, i.e., of giving explanations that are clear for those who already know enough, is quite common in traditional settings, but that its consequences do not often come forward as clearly and immediately as in the above fragment (namely in the form of an explicit withdrawal). I think that implicit withdrawals are its more common consequences, e.g.: not paying attention to the explanations; stop asking oneself and the teacher questions; simply taking the explanations for granted; only trying to meet the teacher's standards and to say what the teacher wants to hear.

I also think that the tendency to give an explanation from above, in the expectation that pupils will be able to follow it, is related to the earlier mentioned tendency to so sequence the content in textbooks that someone who already knows enough understands it, in the expectation that thus presented pupils will at least be able to follow it. Both tendencies, however, at least do not really stimulate pupils to take an active interest in following, simply because no real effort is made to make pupils see the point of following (or to check whether pupils already know enough in order to be able to follow).

6. Towards the end of section 5.2.3 I have pointed at a similar relation. The fact that in the fragment discussed there the teacher did not even seem to consider the possibility that pupils might not quite use their words as he does, is in my opinion related to the failure of common science courses to pay any special attention to the introduction of scientific terms, as part of pupils' entrance into some scientific theory (in the case discussed there: Newtonian mechanics).
Cookbook experiments
I think that also the experimental work in traditional settings does not really involve them in the development of their learning process with respect to content. For the experiments that are performed by the teacher are usually part of an explanation from above, in which the teacher explains the experimental setting, indicates what to observe, draws the conclusions, etc, while the pupils sit and watch. The situation is not essentially different, moreover, concerning the experiments that the pupils themselves perform. For usually, and up to university levels (see, e.g., van Keulen, 1995), these experiments are of a cookbook nature: it is prescribed, step by step, what to do, and not infrequently also what to perceive and conclude.

Thus, pupils not only do not really learn to experiment (to plan, devise, control, etc), but also do not really come to appreciate the point of experimentation in science. It may even be said that in traditional settings experimentation does not play a functional role in pupils' conceptual development. Although experimentation may, e.g., serve to bring some variation in lessons or to increase pupils' ability to handle equipment, as far as following the story of the authors is concerned, I think it does not really matter whether the experiments are actually performed (by teacher or pupils) or just verbally explained by the teacher and read by the pupils.

Emphasis on (the right answers to) exercises
I think it is a familiar fact that in traditional settings there is an emphasis on exercises. It is also in these exercises that, in a sense, the pupils take an active interest. It is not so much that the exercises contribute to pupils' taking an active interest in the development of their learning process with respect to content: the problems that are posed in the exercises commonly are not pupils' problems; they are usually simply presented to pupils, without any attempt to give those a point for pupils; instead the problems are most often pre-fabricated from above such that the theory can be applied in a standard way; the answers to the exercises are usually explained from above, in order to clearly bring forward the standard ways of applying the theory, etc. I think the pupils rather take an active interest in the exercises because those are related to the tests. It is in their best interest, so to say, to try to meet the teacher's standards by training themselves to solve problems like the teacher has solved similar ones. For if, with the help of the teacher, they manage to find out how to solve the standard problems, that will increase their chances at getting sufficient results at tests. In the worst case, the whole point of their learning process for pupils reduces to getting the right answers, in one way or another, to the exercises.

I think that this emphasis on exercises (at least partly) accounts for the familiar finding of science education research that, on the one hand, pupils generally make some progress in solving standard problems but, on the other, little conceptual progress (see section 5.2.2 for an example). In particular, as remarked in section 5.2.3, the emphasis may both account for and mask their limited conceptual progress. In the worst case, the result may be, e.g., applying formulas without insight, memorizing tricks to solve standard problems, verbalism, or compartmentalization. As Poincaré has put it for the case of mechanics: "There is one thing that strikes me, and that is, how far young people who have received
a secondary education are from applying the mechanical laws they have been taught to the real world. It is not only that they are incapable of doing so, but they do not even think of it. For them the world of science and that of reality are shut off in water-tight compartments” (1952, pp.137-8).

5.3.2 Approaches that centre around ‘overcoming alternative beliefs’

In recent years some approaches to planning and guiding science education have been proposed, usually under the banner ‘constructivism,’ that, as far as I understand them, capitalize on the idea that what pupils already know is often in contradiction to the scientific knowledge that they are to learn. One may think here of the status-changing-model proposed by Posner et al (1982), of conflict strategies (e.g., Nussbaum & Novick, 1982) and bridging strategies (e.g., Clement, 1993), of the constructivist teaching scheme proposed by Driver & Oldham (1986), and so on. The emphasis in all of those is, in one way or another, on the alternative beliefs that pupils are to overcome in their process of learning science. I will not comment in any detail on those approaches, most of which are of a rather general nature, but just make some general comments on them and then discuss in somewhat more detail a concrete constructivist teaching sequence.

Let me begin with the general comments. The first one is that in all of the above approaches pupils are given the opportunity to take a much more active role than in a traditional setting. They are, e.g., challenged to engage in activities such as group discussion, designing posters and predicting the outcome of experiments. It turns out that pupils are not only willing and able to take a more active role, but also enjoy that. All this is very positive, of course, because it will increase their involvement in the process. So concerning this aspect of encouraging pupil contributions I am with those approaches.

My second comment is that concerning the other general aspect that those approaches have in common, namely their emphasis on the alternative beliefs that pupils are to overcome, I am not with them. In section 2.2.3 I have tried to illustrate at a few concrete cases that pupils' existing ideas are quite alright and not, as held by proponents of the above approaches, alternative or in contradiction with scientific knowledge. In chapter 4, moreover, it has been argued at some length that correct interpretation forestalls the possibility of finding that a great deal of the beliefs of others are incorrect. So, according to me, much of the point of the above approaches falls away. Although, as remarked in section 2.2.3, I do not mean to imply that pupils will never have to subtract anything from what they believe, it makes no sense to centre an educational approach around pupils' supposedly alternative beliefs. As suggested in section 2.2.3, we should rather search for an approach whose emphasis is on making pupils want to add (substantially) to what they already believe in a way that leads them to a proper understanding of scientific knowledge.

Let me now discuss a paradigmatic example of a concrete teaching sequence that centres around pupils' supposedly alternative beliefs, namely the CLISP-approach to teaching the particulate theory of matter (1987). I will argue that this approach, precisely because of its emphasis on the supposedly alternative beliefs that pupils are to reject in favour of
appropriate scientific ones, fails to involve pupils in a learning process that might eventually lead to a proper understanding of scientific particle models. As a side-line I also indicate what, according to me, the educational task of making pupils see the point and direction of such a process consists in. In doing so it will also come forward that this is a non-trivial task.

Let me first briefly describe how the devisers of the CLISP-approach themselves account for it (see, e.g., Driver, 1988; Johnston, 1990; Scott, 1992). The approach begins with asking pupils for their own ideas about a number of simple phenomena relating to the behaviour of matter (e.g., how smell reaches you). By means of a number of theory making games that are set in non-scientific contexts (e.g., solving a murder mystery), pupils are then encouraged to reflect on their understanding of theories and how those are developed. Next pupils are asked to put forward their own ideas about the properties of solids, liquids and gases and are stimulated to reach a consensus on a pattern of properties. Subsequently pupils are to generate a theory as to what solids, liquids and gases are like inside, while they are reminded of the general nature of theory making and encouraged to base their theory making in the case at hand upon the pattern of properties of solids, liquids and gases. Although up to this point pupils are left completely free in what they bring forward, it turns out, as was expected and/or intended by the devisers, that in a wide range of classes pupils reach consensus on a similar sort of pattern of properties (e.g., solids have a definite and fixed shape, liquids take the shape of the container, gases have no shape but rather completely fill the container), that they generate particle models in order to account for the behaviour of solids, liquids and gases as described by the pattern (e.g., a solid cannot be compressed because its particles are so close together that they cannot be pushed any closer), that some of their particle ideas are alternative (e.g., they attribute macroscopic properties such as expanding to particles or hold that there is air between particles), and that some ideas of the school science view are lacking in their particle models (e.g., particles have intrinsic motion). The heart of the CLISP-approach then consists in making pupils remove their alternative ideas and adopt the appropriate scientific ones (e.g., by thought experiments to encourage them to consider the possibility that there might be nothing between particles, by diffusion demonstrations to make them recognize that particles have intrinsic motion, or by direct explanations of what scientists think).

A first thing to note about this account is that particle ideas or particle models are attributed to pupils because they use words like 'atom,' molecule,' or 'particle,' and/or draw discrete entities in their pictures of what something is like inside. Furthermore, some of their particle ideas are counted as alternative because they attribute macroscopic properties such as melting or expanding to particles.

Now, one is of course free to call what pupils bring forward 'particle ideas' or 'particle models,' but I think one should then also clearly bear in mind that their ideas are not about the particles that figure in scientific particle models and that their models are of a different nature than scientific particle models. For, as already explained in section 2.2.3,

7. Similar arguments can be given concerning other concrete teaching sequences with the same emphasis.
if one clearly separates the notions of belief and meaning, it is clear that from the way pupils use words like 'particle of ...' or 'atom of ...,' one cannot do better, in order to make them make sense, than interpret those as 'tiny bit of ...'. So the statement that pupils come up with ideas about particles/atoms, some of which are alternative, then simply amounts to the statement that pupils believe that a substance can be divided in little bits that, apart from their size, are just like larger amounts of the substance (have the same macroscopic properties, are subject to the same macroscopic regularities, and so on). Their particles simply are small-scale macroscopic objects, and their particle models simply are macroscopic accounts.

However, because of its emphasis on the supposedly alternative particle ideas that pupils are to reject in favour of appropriate scientific ones, the CLISP-approach in effect does equate pupils' particles to the particles that figure in scientific particle models, and does treat their particle models as on a par with scientific particle models. Or, to put it from the pupils' point of view: in the CLISP-approach they are to replace some of their existing ideas about their particles by other ideas about their particles, which are then called 'scientific.'

So in my opinion the CLISP-approach misfires. If appropriately interpreted, there are no alternative beliefs to overcome (e.g., there is no need to make pupils abandon the idea that their particles expand when heated) and to be replaced by 'scientific' ones (e.g., there is no need to make pupils learn that their particles have intrinsic motion or that there is nothing between their particles). Moreover, by unjustly equating pupils' particles to the particles that figure in scientific particle models and by treating their particle models as on a par with scientific particle models, the CLISP-approach also cannot lead to a proper understanding of scientific particle models. At best, pupils will arrive at a hybrid between their particle models and scientific particle models. So it comes as no surprise to me that between two parallel groups, of which one used the CLISP-approach and the other the school's traditional approach, "there was little difference ... overall in the conceptual change produced" (Driver, 1988).

Let me now close this section with an indication of what the educational task of making pupils see the point and direction of a process that eventually does lead to a proper understanding of scientific particle models might consist in. I think for instance, that it should not only become clear to pupils that devising a scientific particle model is a form of theory making that, just like e.g. solving a murder mystery, involves framing tentative hypotheses on the basis of available clues etc, but foremost also that it is the making of a theory of a special kind and that making it of this special kind imposes constraints on the framing of hypotheses.

What is special about a scientific particle model, or at least a classical one, is that it aims to explain, under the assumption that an object is a certain collection of particles with specified masses, all macroscopic changes of that object solely in terms of changes of position and velocity of those particles due to their mutual interactions. The explanation, moreover, is also of a special kind and involves the use of hypotheses of two kinds: hypotheses that allow one to derive, given the positions and velocities of the particles at some time, their positions and velocities at a later time (e.g., hypotheses concerning the
way the particles collide, or concerning the interactions between the particles); hypotheses that link the state of the collection of particles to macroscopic properties of the object (e.g., the mean kinetic energy of the particles in the collection is the temperature of the object). This crudely indicates the general form of any scientific particle model.

The above can also be said to indicate the general framework within which further specific hypotheses are to be made in order to arrive at some specific scientific particle model. I therefore think that the above mentioned educational task, of making pupils see the point and direction of a process that eventually does lead to a proper understanding of scientific particle models, consists in making pupils arrive at a sufficient insight in why the general framework is as it is. For once they have this insight, what they are going to do next, namely devise and modify specific scientific particle models, can be given a point that they understand, while they are then also provided with a sense of control over what comes next in that they themselves can judge whether the further specific hypotheses that are made satisfy the constraints the framework imposes. The framework will then function, so to say, as a stable background that enables pupils to perceive the further process as an internally coherent one with a certain direction: the specific models may change in order to explain better or more, but the general framework remains the same.

Meeting the educational task, i.e., making pupils arrive at a sufficient insight in why the general framework is as it is, is of course far from simple. Among other things, the following should become clear to pupils. Why one would want to improve on macroscopic explanations of macroscopic phenomena in the first place. Why, if there is a need for improvement, it is plausible, in order to attain the desired improvement, to assume that an object is a collection of particles. In what sense these particles differ from

8. Note, first of all, that the particles that figure in any such model are not pupils’ particles. Within any such model it simply is not allowed to use in an explanation, e.g., the hypothesis that particles expand: everything has to be explained solely in terms of changes of position and velocity of the particles due to their interactions. Furthermore, the only property that is attributed to the particles in any such model is that they have a fixed mass. This is not to say that, e.g., when picturing the particles, one is not allowed to attribute colour and shape to them or even to draw something other than particles between them, as long as in explanations one makes no use of the colour and shape thus attributed to them or of the something that is imagined between them.

Note, further, that the above scheme not only indicates the general form of classical particle models but also applies, with appropriate modifications, to the formalism of quantum field theory. One modification in that case concerns the properties that are attributed to the particles. Apart from their mass, also their charge, spin, charm, strangeness, etc are specified. Another modification concerns the hypotheses of the first kind: in quantum field theory the interaction between the various kinds of particles are specified in the form of a particular Lagrangian density, by means of which it is possible to calculate, by specified procedures, the transition probability from an initial many particle state to some final many particle state. The initial many particle state specifies how many particles of this kind with this momentum, this component of the spin along a specified direction, etc, how many of that kind with that... etc, are present before the interaction takes place; the final many particle state how many particles of this kind with this... etc, are present after the interaction has taken place. One of the differences with a classical model is that there may be a non-vanishing transition probability to a final many particle state in which a different number of particles (of some kind) is present than in the given initial many particle state.
small-scale macroscopic objects. Why one wants to give explanations solely in terms of changes of position and velocity of the particles, and why it is plausible to expect that all (or at least a great number of) macroscopic changes can be explained in these terms. Why, in order to give such an explanation, one needs the two kinds of hypotheses mentioned above, and what the explanation then consists in. How further specific hypotheses can be arrived at. In what sense some specific particle model can be called better than another one.

I hope this suffices to not only make clear that the real educational task is non-trivial, but also that the CLISP-approach does not meet it at all and, in fact, draws one's attention away from it. What I would like to retain from the CLISP-approach is to give pupils an active role in the process. They enjoy that and will thus be more involved in the process. But whereas in the CLISP-approach their involvement consists in their bringing forward ideas about their particles, I would like it to consist in their seeing the point and direction of, and their having control over, constructions and reconstructions of specific scientific particle models.

5.4 Didactical structures

5.4.1 A problem-posing approach: making pupils want to add to their conceptual resources, experiential base and belief system

As will have become clear from the preceding sections, I think that the main possibilities for improving science educational practice at a content-specific level are to be sought in appropriately taking into account the content-directed evaluative attitudes (and not, for instance, in taking into account supposedly alternative beliefs). That is, as far as the cognitive attitudes are concerned it has been argued that pupils' science learning should be thought of as in the crude picture presented in section 5.1.3: it is a process in which pupils, by drawing on their existing conceptual resources, experiential base and belief system, come to add to those (with accompanying changes of meaning). What I think needs to be added to this picture is that, if the process is to make sense to them, pupils must also be made to want to add to those (with accompanying changes of meaning), in a way that leads to a proper understanding of science. An approach to science education that explicitly aims at this I call problem-posing. If one adopts this approach, one will not unquestioningly assume (as in many traditional science curricula) that pupils simply stand ready to absorb new knowledge, such that all one has to do is present them this new knowledge. Rather, the emphasis of a problem-posing approach is on bringing pupils in such a position that they themselves come to see the point of extending their existing conceptual resources, experiential base and belief system (with accompanying changes of meaning) in a certain direction. Let me give some examples.

In section 5.2.4 it has been argued that if the introduction of a scientific term is to make sense to pupils, it should have a point for them. They should feel some kind of need for, or at least have good reasons for, having available a term of the kind one intends to introduce. This need or these good reasons are to create a place in pupils' conceptual
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apparatus for the term to be introduced to occupy. The need or good reasons, moreover, will in general have to be induced in one way or another. For if they already existed, i.e., if the place was already created, it most likely would already be occupied, i.e., there most likely would be no need to introduce the scientific term because pupils would already have it at their disposal.

In general there will also be no existing want of pupils to learn the particular content one intends to make them learn, if only because they do not yet know that particular content. So in general one will have to induce such a want. A first step in this direction might consist in connecting the content that one eventually intends pupils to arrive at with their existing interests. These existing interests may then induce in pupils, what may be called, a global motivation for at least beginning to study the topic at hand, and at the same time provide them with a, without doubt still very vague, sense of purpose and direction concerning where their study will lead them to. As already noted, this can only be a first step.

Further, and more specific, wants will have to be induced in the further process, e.g.: a want to enlarge their experiential base in a certain direction, in order to find an answer to a question that has, in turn, been induced earlier in the process. In order to comply with that want they may subsequently devise an experimental setting, by means of which they expect to so enlarge their experiential base that they will find an answer to the question. They will then evaluate their subsequent experimentation in the light of this expectation, as a result of which a need may come forward for an improvement of the experimental setting, for further experimentation, and so on. In the course of their experimentation, moreover, they may come to recognize regularities and come to frame inductive hypotheses. Since they have then played an active part in the establishment of the hypotheses (on which evidence the hypotheses are based and how the evidence coheres with the hypotheses), they will also appreciate how, when, and when not to apply those. Perhaps they also come to see some of the limitations of the established hypotheses, which may then, in turn, create a need to improve on those. And so on.

From the above examples it will be clear that it is an essential ingredient of a problem-posing approach that pupils' reasons for being involved in a particular activity are induced by preceding activities, while that particular activity in turn, together with its preceding activities, induces pupils' reasons for being involved in subsequent activities. Thus their process of science learning is, at any stage, provided with a local point, which is to locally involve them in the development of the process with respect to content. Another essential ingredient of a problem-posing approach is that their process is provided, at appropriate stages, with a global point, e.g. by making them see a connection with existing interests, or by bringing them in such a position that they themselves come to pose a main problem that they intend to work on. A global point is to induce a (more or less precise) outlook on the direction that their process of science learning will take, and thus to increase their involvement in the further development of the process with respect

Note that thus, other than in traditional settings (cf section 5.3.1), experimentation does play a functional role in the development of pupils' learning process with respect to content.

Ten Voorde (1977) speaks in this respect of 'being prepared by' and 'preparing for.'
to content.

It is perhaps worth noting that it is not the point of a problem-posing approach that everything should come out of the pupils themselves. If, for instance, pupils themselves have framed some problem they intend to work on, the teacher might well offer some elements of its solution. The point then rather is (1) that the teacher can explicitly offer these elements as possible elements of a solution to their problem, (2) that the pupils, given that they intend to solve the problem, will be willing to investigate whether these elements do contain clues for a solution, and (3) that they will be able to do so, given that they have a clear understanding of the problem since they themselves have formulated it. More generally, the point of a problem-posing approach is to enable pupils to themselves perceive their process of learning science as an internally coherent one with a certain direction, which in important respects is being driven by their own questions and over which they have some control.

5.4.2 Planning pupils’ science learning as a dynamical process of rational accommodation

In planning a problem-posing approach to teaching some scientific topic, one not only needs to think about which new scientific terms will have to be introduced to pupils, which experiments they will have to perform in order to learn which new knowledge, etc. Irreducibly related to that, one also needs to think about the interests, aims, desires, intentions, etc, that one will have to link up with, change or induce. A detailed planning of how, for the topic at hand, a given order of tasks and teacher interventions, in relation to pupils’ reactions to those tasks and interventions, is expected to lead to which changes of meaning, additions of belief, changes of intention, etc, I call a didacti cal structure of that topic. It contains, for example, statements of the following kinds: which experiments pupils will think of, given what they believe and what they want to achieve; which conclusions and questions they will formulate as a result of their experimentation; what point those questions will give to the next task, etc. Note that if we are to account for such statements, we will have to make such assumptions as the following: when thinking of experiments pupils will think of ones that, given what they believe, can reasonably be expected to lead to a desired result (e.g., an answer to a question they themselves have posed); they will base their hypotheses in a sound way on the relevant evidence; they do not accept contradictions in their system of beliefs and, if such threaten to occur, intend to resolve the matter (e.g., by withdrawing an over-generalization), etc. What such assumptions come down to, is that we can view pupils as rational agents, who share with us a largely correct view of the world and basic standards of rationality.

When pupils are viewed as rational agents, the development of their learning process with respect to content can be planned as a dynamical process of rational accommodation, in which pupils intentionally act to keep their system of thoughts as coherent as possible by adjusting it as rationally as possible as new thoughts are thrust on them. The outcome of an experiment they have performed for reasons that made good sense to them, for example, will cause them to add to their stock of beliefs. Rational accommodation of that belief may lead to new questions that pupils want to find an answer to, to the formation of an intention to focus their attention on some aspect of an
event, to their seeing the point of classifying events in a particular way, etc.

Let me make some additional comments. Note, first of all, that it is only when the evaluative attitudes and changes therein are explicitly taken into account in pupils' science learning, that it makes sense to try to give a dynamical account of the development of their learning process with respect to content. This observation corresponds to, and is inspired by, Davidson's observation that the evaluative attitudes do also play a fundamental role in interpretation (cf chapter 4 and appendix 1).

A second comment is that, as argued in chapter 4, the policies that are required in a process of rational accommodation derive from understanding someone else, and making oneself understood by others, as a rational agent. These policies, which in chapter 4 have been taken together under the heading 'principle of charity,' are therefore most naturally called for in an interaction with others. For this reason I think pupils should be allotted an active role in their learning process and, in particular, be challenged to work and discuss with each other. An additional reason, already mentioned in section 5.3.2, is that pupils generally like group work and having an active role, and thus will be more involved in the process when they are working in groups and are given the opportunity to take an active role.

A final comment is that a didactical structure of some scientific topic (as a planning of pupils' science learning in the form of a dynamical process of rational accommodation) should not be confused with a rational reconstruction of the topic of the kind mentioned towards the beginning of section 5.3.1. The point of the former is to plan pupils' process of learning the topic in such a way that all along the pupils themselves know what they are doing and why, and that by building on what they already know are given ample chance to further extend what they already know, driven by what they themselves are doing, by their reasons for doing it, and by the conclusions they reach and problems they encounter as a result of doing it. The point of the latter is to reconstruct the topic in hindsight, not by describing the actual route along which it has been mastered but, having already mastered it, by conveniently building it up from first principles. As such, it may have a place in a problem-posing approach, but only towards the end of the learning process, as a kind of summarizing activity.

5.4.3 An outlook
What I have written above on a problem-posing approach and on didactical structures is rather programmatic (and intended as such). What it suggests, and what I take as an important task of science educational research, is to devise, empirically test, improve, etc., concrete didactical structures, with as eventual aim an empirically based didactical structure of science (Lijnse, 1995), which I think of as constituting science educational theory. In the remaining chapters I will take a few steps in this direction. In chapter 6 I will mention some possibilities for outlining a didactical structure at a global level. In chapter 7 I discuss some aspects of devising a didactical structure. In chapters 8 and 9 I present and evaluate a concrete didactical structure, namely of the topic of radioactivity. In chapter 11 I present some (preliminary, fragmentary and immature) suggestions for future steps.

Let me close by making a few remarks on two aspects that I have neglected up to now:
the role of the teacher and the role of teaching materials in a problem-posing approach. Although their roles are different than in traditional settings, in a problem-posing approach too both the teacher and teaching materials play an important role, namely in guiding and structuring the process of rational accommodation that pupils establish and give shape. Whereas in a traditional setting the teaching materials usually consist in a textbook, whose main line is a story in which the authors present, explain and illustrate the theory, and which the pupils are supposed to follow (cf section 5.3.1), in a problem-posing approach the teaching materials consists in a collection of tasks, whose purpose is to help pupils in writing their own story (cf section 8.2). In chapter 10 there is more on the role of the teacher. Let me here just note that, whereas in a traditional setting the teacher's role often comes down to explaining from above (cf section 5.3.1), in a problem-posing approach the teacher's role is rather one of, what may be called, guiding from below.

10 The teacher's role

10.1 Introduction

In the preceding I have repeatedly pointed at (the importance of) the role of the teacher. In chapter 8 I have noted that the teacher's role in working with a didactical structure as the one outlined there is different from the teacher's role in more traditional approaches. For example, giving pupils more control over, and thus more responsibility for, their progress with respect to content implies a shift in the teacher's control and responsibility: a shift towards procedural control and responsibility for managing the process. In section 7.4.3 I have noted that it also involves a shift from wanting to make pupils say and do particular things (with the associated danger of 'hearing and seeing much more' in what the pupils say and do), towards the teacher's being more prepared to find out what the pupils actually say, believe, want, etc and to (re)determine his or her goals on the basis of what they actually say, believe, want, etc. In section 7.3 I have noted that even if a didactical structure as such can be judged as 'good enough,' which is the maximum attainable, it still needs the creativity of a good teacher for it to lead to successful education.

In section 7.3 I have also noted that at least the evaluation of a didactical structure should take place in cooperation with the teacher that has worked with it. In section 9.2.1 I have mentioned that I cooperated quite closely and intensively with one teacher. He not only worked with the second version of the didactical structure outlined in chapter 8, but had also worked with the first version, and was involved in the construction and evalu-
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ation of both versions. By this cooperation it was tried to secure as well as possible that the teacher had made himself so familiar with the essence of the didactical structure and his role in it that he would not deviate essentially from it.

In this chapter I somewhat elaborate the above themes. But I now first briefly report on some experiences during the first year of my research, which have made me realize that a cooperation with a teacher should be very carefully set up and that it should be set up with a teacher that has good managing qualities.

In the first year of my research I observed two series of lessons in middle ability classes that used the unit *Radiation, you cannot evade it...* (Knoester & Lancel, 1988; cf section 3.3 for some findings of the observations). One of these series was taught by a teacher that possibly was to further participate in my research, and the main aim of my observation of the series of lessons taught by her was to find out whether there was a basis for further cooperation. Before the series of lessons I told her my at that time still very vague ideas about the aim and nature of my research: I wanted the pupils to meaningfully learn about the topic of radioactivity, and for that purpose one should somehow start from pupils' existing knowledge; I later was going to write a series of lessons on the topic myself, and to get some ideas for that I would like her to try out some additional activities while teaching the unit *Radiation, you cannot evade it...*. The teacher then indicated that she was somewhat sceptical about my aim. Her scepticism did not so much consist in a denial that pupils have ideas of their own, but rather in her experience that the gap between their own ideas and those of physics was rather large and hard to bridge. In fact, she indicated that in her worst moments she sometimes sighed that all that can be achieved is that pupils learn to solve standard exercises for examinations. Nevertheless, she said that she herself constantly tried to bridge the gap and so she was quite prepared to participate and to try my proposals. In fact, she already saw the unit *Radiation, you cannot evade it...*, of which she was one of the authors, as making a serious attempt to bridge the gap.

During the series of lessons her scepticism was not noticeable at all (at least not by me). She was enthusiastic, put quite a lot of time in it, tried to carry out my proposals for additional activities as well as possible, and regularly indicated to enjoy it all. I too was satisfied about the series of lessons in the sense that I was confirmed in my suspicion that the structure of the unit I was going to write myself had to be quite different from the structure of the unit *Radiation, you cannot evade it...*. Moreover, from how the tried out additional activities worked out I got some ideas about activities that might be useful for the unit I myself was going to write. There was also a source of trouble, however, relating to the teacher's order-keeping abilities. The situation in her classroom could most of the time best be described as a 'non-aggressive disorder' (cf Créton & Wubbels, 1984). She did not show much leadership, and quite often the lessons were poorly structured. She generally tolerated quite some disorder, and the pupils very often were not task-

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1. Because the unit is based on micro-level explanations (cf section 3.2), I myself could not see it that way.
2. Some of the tried out additional activities are indeed precursors of activities that figure in the first and/or second version of the didactical structure.
oriented. Although she was quite concerned about the class and willing to explain things over and over to pupils who had not been listening, the whole situation was usually so unstructured that only the pupils in her direct neighbourhood were attentive, while the others would do other things such as talk with each other or make some homework. They were not provocative, however, i.e., their other activities were not directed against her, and she usually ignored them while talking loudly to the pupils near her. Her few efforts to also involve the other pupils were usually delivered without emphasis and mostly had little or just a short-term effect. Though most of the pupils seemed to like her and she certainly liked most of the pupils and took a great deal of interest in them, the interaction between her and the pupils very often resulted in a non-productive equilibrium in which all of them sort of seemed to go their own way. The teacher's limitations especially came forward during the additional activities, most of which were of the 'class discussion'-type. For even though the teacher really attempted to involve all pupils, she mostly did not succeed. The result was that the discussion was also hard to follow for the few pupils that were attentive, because of the many times that it was interrupted by the teacher's (vain) attempts to call the other pupils to order. The teacher was well aware of all this, and although she herself also did not find her teaching style particularly good, she also maintained that, at least for the time being, it reflected her best way of surviving in the classroom. So if there was to be a further cooperation with this teacher, it would have to be accompanied by an in-service training in managing order problems.

However, and at the time quite unexpectedly for me, the teacher herself decided that there was not going to be a further cooperation. The results of the test that followed the series of lessons had reawakened her old scepticism. The test consisted for about two-third of rather standard tasks (about half-life, the different penetrating power of the different kinds of radiation, the number of protons neutrons and electrons that a given isotope consists of, etc, i.e., exercises of the type that could come up in the examination), and for about one-third of tasks that demanded some insight (in e.g. the point of distinguishing between contamination and irradiation). It turned out that generally the pupils answered the standard tasks sufficiently well, though not overwhelmingly so, but the insight-tasks rather poorly. I did not make much of those test results, or at any rate I found them quite understandable. For, as I have already noted, the additional activities, which explicitly aimed at insight, went past most pupils. Furthermore, the additional activities were not backed up by worksheets and also did not fit nicely into the unit Radiation, you cannot evade it... For me, all this meant that adding just a few activities was not sufficient. Although some of them might be useful, they had to integrated in a structure that was quite different from the structure of the unit Radiation, you cannot evade it..., and had to backed up by written material that would serve as a hold for pupils. In short, I would have to write my own series of lessens and that was precisely what I was going to do. For the teacher, however, the results of the tests confirmed her earlier scepticism. Below I give some fragments of her verbal explanation of her decision to quit.

If I look at the enormous amount of time I have spent on it and that the part that does later come up for examination, that already that part is not really right, and that this [the part relating to insight, KK] apparently also has not got across, then I say... well, this is wrong, this is a waste of my time, period.
These pupils [middle ability pupils, KK] have been taught tricks and memory aids from primary school on, otherwise they do not make it through that school. And then you cannot in six weeks all at once aim at insight... and forget that there is something like an examination waiting for them that they will have to do. So I think that in this context it is indeed unfeasible [to aim at insight, KK].

I have followed your road all along, and if I now look at what it has yielded then I think... well, if I had done it my way it would have taken me, a, less time and the test would have been made better. [...] Not the second part [the insight-tasks, KK], the multiple choice [the standard tasks, KK]. Then I would have shifted the emphasis. And then I think, simply from the point of view of my pupils, that is what they have to know. And then I will do my best to also bring in those other things, but already beforehand I accept that that will largely be a wasted effort. I told you so at the beginning: you can try it, but I don't think that it will work. And then I am working on it and then I am really enthusiastic and then... and I did terribly enjoy doing it, I would like to always work like this, but... well, I just notice that it has had little or no effect up to now.

I think we have done all that we could have done in this context [she later specifies this to: with these pupils, in these times, with this previous education; KK]. I would not know what else you should have done.

Whereas for me the whole thing still had to begin, for the teacher it was all over; whereas I thought the time was ripe to lay my own road, she thought she had already followed my road all along, and with little or no effect.

In order to find a new teacher some heads of physics were approached with the question whether they knew a good and experienced teacher that might be willing to participate in an educational experiment. In this process the teacher that I worked with for the rest of my research came forward. In section 10.2, this teacher is characterized. In order to carefully prepare a productive working relation, the teacher and I took quite some time to get acquainted. In section 10.3, I report on this preparatory period. In section 10.4, I go into some aspects of our cooperation during the (re)construction of the didactical structure. In section 10.5, finally, I try to go beyond this one teacher and more generally address the question what it means for a teacher to work with a didactical structure that is 'good enough.'

### 10.2 Characterization of the teacher

The teacher I worked with was born in 1945. He graduated from a college of education in 1967, but only taught for about two months at a primary school. By means of some refresher courses he in 1969 acquired a qualification to teach physics and chemistry at the LBO and MAVO types of education and at the first three years of the HAVO and VWO types of education (cf section 9.2.1). From 1969 to 1984 he taught physics and chemistry at a school which consisted only of a MAVO-stream. In 1984 this school merged with another school to form a school for MAVO, HAVO and VWO. It is at this school that up to this day he has taught physics and chemistry at the levels he is qualified for. It is thus also the school at which he has worked with the various versions of the didactical structure. The above may suffice to illustrate that he is a very experienced teacher.
The head of physics that recommended him also assured us that he is a good teacher, i.e., a teacher of whom pupils say that he is a good teacher. I also got this impression by observing some of his lessons in the preparatory period (cf section 10.3). There was a pleasant and productive working atmosphere in his lessons, there were hardly any order problems and if some cropped up the teacher usually managed to immediately and effectively deal with them. I would have characterized him as 'strict, but nice' or 'nice, but strict.' In order to somewhat further substantiate these claims, the so called Questionnaire on Teacher Interaction (QTI) was administered to the teacher and several of his classes. The QTI, which was developed in the early eighties by Créton & Wubbels (1984), is an instrument to characterize the affective climate of the learning environment, as perceived by the participants (pupils and teacher). If we roughly discern two aspects of teacher behaviour, a methodological one that relates to content presentation and instructional methods and an interpersonal one that has to do with the teacher's interpersonal actions that create and maintain a positive classroom atmosphere, the QTI can be said to capture the latter aspect of teacher behaviour. By discerning these two aspects I do not mean to deny, of course, that they are interconnected. Wubbels & Levy (1993b) note in this respect that "[i]f the quality of the classroom environment does not meet certain basic conditions the methodological aspect loses its significance." In fact, concerning the teacher whose lessons I observed during the first year of my research I have made a similar remark (cf section 10.1).

The QTI leads to a characterization of interpersonal teacher behaviour in terms of eight different types of interpersonal behaviour, which can be represented in a two-dimensional plane (cf figure).
Figure 10.1 The model for interpersonal teacher behaviour. (Figure 2.2 in Wubbels & Levy, 1993a.)

The two dimensions of the plane have been labelled 'proximity' and 'influence.' The 'proximity-dimension' indicates the teacher's degree of cooperation with or closeness to pupils, on a scale between Opposition (O) and Cooperation (C). The 'influence-dimension' indicates the extent to which the teacher directs or controls the interaction with pupils, on a scale between Submission (S) and Dominance (D). In figure 10.1 the eight different types of behaviour are represented by the eight sectors DC, CD, etc, "according to their position in the coordinate system (much like the directions on a compass). For example, the two sectors DC and CD are both characterized by Dominance and Cooperation. In the DC sector, however, the Dominance aspect prevails over the Cooperation aspect" (Wubbels, Créton, Levy & Hooymers, 1993). In figure 10.1, each of the eight sectors is also characterized in words, both briefly (DC by 'leadership,' CD by 'helping friendly,' etc) and somewhat more elaborately in terms of characteristic teacher behaviour.

The questionnaire itself, the QTI, of which there is a Dutch and an American version, "is divided into eight scales which conform to the eight sectors of the model. In the Dutch version each sector scale consists of about ten items (seventy-seven in total) which are answered on a five-point Likert scale. The American version has sixty-four items and a similar response scale" (ibid). For a discussion of the reliability and validity of the QTI, I refer to Brekelmans et al (1990).
Each completed questionnaire yields a set of eight scale scores which are then combined into a profile. Scale scores equal the sum of all item scores and are reported in a range between zero and one. A scale score of 'one' indicates that all behaviours in a scale are always (or very much) displayed. A 'zero' is the opposite: the absence of scale behaviours. The profile represents the teacher's communication style as perceived by the teacher or his or her students. It is usually depicted in a graph with scale scores represented by shading in each sector (Wubbels, Créton, Levy & Hooymayers, 1993). Figure 10.2 contains three examples of such graphically represented profiles. They derive from three different types of data. Students in The Netherlands, the United States and Australia were asked to rate their best teachers on the QTI. Also, teachers in the three countries provided self-perceptions about their ideal behaviour. Finally, a smaller group of Dutch students completed the QTI for a teacher they thought of as their worst. Figure [10.2] shows the average scores for these three groups in the United States. The results are similar for the other countries (Levy et al., 1993). Figure 10.3 may be another profile of interest. It shows the average of 463 students' perceptions for a random sample of 118 Dutch teachers (ibid). So in a sense it represents the communication style of the mean Dutch teacher, as perceived by students.
By using a variety of clustering procedures and similarity measures, Brekelmans (1989) has established a reliable and stable typology of eight types of communication style, such that each profile out of a large number of profiles of Dutch, American and Australian teachers belongs to one of these eight types. By combining QTI data with descriptive data of classroom atmosphere, Brekelmans has also given a description of each of the eight communication styles in terms of teacher/student behaviours and learning environment characteristics. Brekelmans et al (1993) contains, for each of the eight communication styles, both the mean profile corresponding to it and its description in terms of learning environment characteristics.

I hope the above gives sufficient information on the QTI. As I have already noted, the QTI has also been administered to the teacher and to several of his classes that worked with a version of the didactical structure.
The Authoritative atmosphere is well-structured, pleasant and task-oriented. Rules and procedures are clear and students don't need reminders. They are attentive, and generally produce better work than their peers in the Directive [another category in the typology, KK] teacher's classes. The Authoritative teacher is enthusiastic and open to students' needs. He or she takes a personal interest in them, and this comes through in the lessons. While his or her favourite method is the lecture, the Authoritative teacher frequently uses other techniques. The lessons are well planned and logically structured. He or she is considered to be a good teacher by students.

The teacher's ideal communication style (i.e. the one that corresponds to the profile of figure 10.4a) is of the type that Brekelmans has labelled "Tolerant and Authoritative." In Brekelmans et al. (1993) it is characterized as follows.

Tolerant/Authoritative teachers maintain a structure which supports student responsibility and freedom. They use a variety of methods, to which students respond well. They frequently organize their lessons around small group work. While the class environment resembles Type 2 [the above 'Authoritative' type, KK], the Tolerant/Authoritative teacher develops closer relationships with students. They enjoy the class and are highly involved in most lessons. Both students and teacher can occasionally be seen laughing, and there is very little need to enforce the rules. The teacher ignores minor disruptions, choosing instead to concentrate on the lesson. Students work to reach their own and the teacher's instructional goals with little or no complaints.

Hereby I hope to have sufficiently characterized the interpersonal aspect of the teacher's classroom behaviour. Let me close this section by noting that the quality of the classroom environment that he manages to create is such that the methodological aspect, on which my research mainly focuses, could indeed be given full consideration. In devising the didactical structure we have been in the luxurious position that whatever technique or instructional method we proposed (be it group work, class discussion, experimental work, or complex combinations of these), we could always count on the teacher's ability to satisfactorily handle them.

10.3 A preparatory period

Before the teacher and I decided to cooperate on an educational experiment, we had an exploratory talk in which I told something about my ideas concerning the experiment and the teacher about his attitude towards it. I told him that I wanted pupils to meaningfully learn about the topic of radioactivity, that recent research had shown that this aim was very often not reached (not just for the topic of radioactivity, but for almost any topic), and that part of this failure might be due to the fact that most approaches do not start from where pupils are. It almost seems as though for pupils the scientific knowledge they 'learn' is something alien that only has application in the science classroom. I also told

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3. I want to thank Rob Houwen for the analyses of the QTI data: for producing the profiles like those in figure 10.4, and for determining the type of communication style to which each of them belongs.
him about the cause of our having this exploratory talk: another teacher's decision to quit, and why that other teacher had decided so (cf section 10.1). Of course, I would like to prevent a repetition of that situation. In order to do so I told him I had first of all planned a quite extensive period to carefully prepare a productive working relation. So taking an active part in this preparatory period would be one thing I expected him to do, if he decided to cooperate. Other things would be that he helped in writing new teaching materials (in the first instance in a commenting role), worked with these new materials (while the relevant lessons were being videotaped), etc. What he would get in return were two non-teaching periods and a piece of in-service training that, hopefully, was going to be useful for him.

Of course I also wanted to know how he felt about the aim of my research, however vague it was. In particular I wanted to know, in the context of preventing a repetition of the situation with the previous teacher, whether or not he shared her sceptical attitude. The teacher said to recognize that knowledge does not always function, in the sense that pupils cannot apply it. He told that he thinks that is a problem: it frustrates. So he suspected that he somehow worked on that problem, although it was not a conscious element of his teaching practice. At any rate, from what I had told him he said to have gathered that participating in my research would give him the opportunity to explicitly think and learn about an attempt to tackle that problem, and he certainly did not already beforehand consider such an attempt to be a lost cause. In fact, he said to see no reason why insight would be impossible for middle ability pupils. Finally, the teacher said to hope that by participating in my research he could learn something that might also be of use for other topics than the topic of radioactivity. From this I gathered that at least he had a non-negative attitude towards (the aim of) my research.

On the basis of this exploratory talk the teacher and I decided to cooperate. In this section I report on the first stage of our cooperation: the preparatory period. In section 10.3.1, I sketch the aims, procedure and outline of this preparatory period; in section 10.3.2, I sketch the way it developed and mention some of its main outcomes.

10.3.1 Aims, procedure and outline
The main aim of the preparatory period was to prepare a productive future working relation with respect to writing, trying, etc new teaching materials. In a process in which he came to familiarize himself with (the aim of) my research and I came to familiarize myself with his way of teaching we would have to develop a common way of talking about teaching and learning in general, and about teaching and learning the topic of radioactivity in particular.

The preparatory period took place during the fall of 1989. In that period I visited about one lesson per week, mostly in one of the classes in which later in the school year the first version of the didactical structure was going to be tried. Furthermore, the teacher and I had eleven meetings of about two hours each. The teacher's preparation of a meeting consisted in his doing some homework (of about two hours per meeting). Mostly the homework tasks were given by me, e.g.: study the similarities and dissimilarities between
two units on the topic of radioactivity; study some transcripts of interviews with pupils about molecules or radioactivity and relate these to your own teaching about those topics; study some transcripts of fragments of lessons on the atomic model (what are pupils' difficulties and do you recognize these difficulties from your own experience?); study a description of pupils' existing knowledge about radioactivity (along the lines of section 2.5 of this thesis) and comment on it. Occasionally the teacher also set his own homework task, e.g.: carry out a small scale questionnaire study in one class at his school and analyze the results. My preparation usually took me about one working day. It consisted of things like: selecting useful homework tasks for the teacher; anticipating his reactions to it and thinking of ways to build on that in order to clarify some of my ideas about teaching and learning (the topic of radioactivity); studying the conversation we had during a previous meeting (the meetings were recorded on audiotape), and making a reflective report of it in order to identify themes that deserved a further treatment in later meetings; thinking of ways to integrate what I had noticed during visits of lessons in our meetings.

Some of the themes that came up during the meetings were: the aim of the preparatory period and an outline of it; the tendency to base units on the topic of radioactivity on particle models (cf section 3.2); the way such 'models' are often understood by pupils and its consequences for their learning about radioactivity (cf section 3.3); parallels between the teacher's and my learning process during the meetings on the one hand, and pupils' learning on the other; the teacher's role with respect to content: holding back versus steering; the knowledge that seems to be required for an adequate understanding of (the possible dangers of) daily life situations having to do with radioactivity; the usefulness of the meetings.

The teacher's homework for the final meeting of the preparatory period was to write a review of it: on what he had learned from it, on whether through it he felt prepared for a further cooperation, etc. In the final meeting we discussed his review. The totality of my reflective reports of each meeting can be seen as my review of the preparatory period. Section 10.3.2 is based on it.

10.3.2 Development and outcomes

At the beginning of the preparatory period I had some ideas about themes that I wanted to bring up for discussion (cf the previous section), but I did not really have much ideas about how to structure each of the meetings, about a suitable order in the themes I wanted to bring up for discussion, about useful homework tasks for the teacher, etc. In fact, the latter ideas gradually developed during the meetings and also as a result of my making reflective reports of each of the meetings. Below I sketch and exemplify these developments, the use of my regular visits to lessons given by the teacher, and some of the main things the teacher and I have learned from the meetings.

The structure that the meetings gradually assumed

After a while the structure of the meetings between the teacher and me was based on our awareness that we approached educational matters differently and with different
experiences, and took the form of trying to make explicit each other's approach and experiences while discussing concrete material (transcripts of lessons and interviews with pupils, results of questionnaires, textbooks, things that happened in a lesson I visited, etc). Below I exemplify how an analysis of the earlier meetings gave rise to this structure and how this structure was made explicit.

The first meeting was a brief one and concerned the procedural aspects of future meetings (how often, how long, how much preparation, etc). The second meeting was the first one in which we discussed issues. The theme I wanted to bring up then was the obviousness of the tendency to base a unit on the topic of radioactivity on particle models. In order to first of all make clear this tendency, I selected two such units (the unit in the textbook the teacher normally used and the unit *Radiation, you cannot evade it...*), which, although they are quite different with respect to e.g. content presentation, essentially have the same structure. So the homework task I gave to the teacher was to study those two units and capture the main lines of the way each of them is build up. I expected that thus he would also find that the two units are essentially the same and, in particular, both begin with the presentation of a nuclear 'model.' (This would then allow me to ask whether it is obvious to begin in that way.) More or less for the sake of completeness I added to the homework assignment the question what the differences between the units are. It turned out that the teacher had indeed noticed the similarity in structure, which he framed as 'what atoms are; what radiation is; how radiation emerges; what the effects of radiation are;' but that he was most struck by the differences between the two units. He found the unit *Radiation, you cannot evade it...* much more pupil-friendly, especially for middle ability pupils: better geared to them and more surveyable for them. For it consists of relatively short and easily readable pieces of information, each of which is followed by some questions that directly refer to it, it contains regular and short summaries, etc. The other unit, in contrast, contains many long stretches of text with too high a level of difficulty, which, as was the teacher's experience, a middle ability pupil simply cannot get through.

Our different approach can in this case be characterized as our laying a different emphasis. Although I noticed the difference in content presentation (and had, in fact, selected the two units because of this difference), I emphasized the similarity with respect to structure. And although the teacher noticed this similarity, he emphasized the difference in content presentation. The teacher's emphasis can be said to reflect his practical and pragmatic approach, with an immediate link to his everyday teaching experience. One of the first things he asked me when discussing the two units was: what do you have in mind, something like this unit or something like that one? My own emphasis can be said to reflect my more theoretical approach, which is also related to existing teaching practice but more in the sense of looking at it from some distance and bringing it up for discussion - in this case, the obviousness of the existing tendency to base a unit on the topic of radioactivity on particle models.

What enabled the teacher to also bring in his points was the part of the homework assignment that asked for dissimilarities between the two units. I have already mentioned
that at the time I more or less accidentally included that question in the homework assignment, or had at any rate not included it in order to allow the teacher to bring forward his points. If only for the reason that in a period of getting acquainted the teacher should also be given the opportunity to bring forward his own points, for future meetings I very consciously tried to devise such homework tasks, that the teacher, with his more pragmatic approach, and I, with my more theoretical approach, could each bring forward our own points, thus make explicit each other's approach and experiences, and thus also learn from each other. Indeed, it was not just out of politeness that the teacher was given the opportunity to bring forward his own points, and the fact that in the meetings I naturally had to take the initiative did not imply that only the teacher was supposed to learn something. I also learned from the teacher. The teacher's comparison of the two units, for instance, made me realize that in the later writing of new teaching materials I would have to seriously deviate from my normal writing style. Instead I would have to write relatively short and simply constructed sentences that would have to be organized in a whole that is easily surveyable for middle ability pupils. At least in that respect, so I learned from the teacher, I should take the unit *Radiation, you cannot evade it...* as an example.

In later meetings I also tried to make this structure of our meetings explicit: by illustrating it at examples like the one above; by explicitly telling one another what each learned from the other and how that relates to the other's approach; by drawing parallels between our learning from each other and pupils' learning from their teacher (or teacher's learning from his or her pupils). In the fifth meeting, in which among other things we looked back on the previous meetings, the teacher also recognized the structure that the meetings had assumed:

I do also sense it like that. That we are feeling out, catching up from each other. I hear new things, you learn new things. Obviously you take the initiative. Well, that's how I see it: you are... I'm here for you. I think you have to take the initiative. I think I get all room. If I dwell on something, then there simply is time for that, then we simply keep on talking about that subject. I... up to now... I actually think it's getting easier and easier for me. The first time I thought: Jesus, it looks like an examination or it looks like... I have the feeling that I'm being interrogated about what I do and do not know. And now I don't have that at all. We're simply feeling out: how do we think about some things?

Later on the teacher told me that his initial feeling also derived from his not feeling very safe at the time. He, the dumb teacher, had to go to a place where he did not really belong: The University.

Of course the teacher and I gradually grew closer to each other. When in later meetings we e.g. discussed some transcripts of lessons, the teacher would bring forward points that I also found relevant, and for very much the same reasons. The main difference between us then was that I usually brought forward more similar such points, which the teacher, after I brought them forward, mostly also recognized as similar. At first this difference in quantity gave the teacher the impression that he had not done his homework well enough and, in fact, made him feel sort of guilty. Of course, I then told him that there was no
need for such impressions and feelings. On the contrary, the fact that he focused on very much the same points as I did was evidence for the fact that our approaches converged with respect to some themes. The difference between us then no longer was a matter of different approaches, but rather of different amounts of time spent on homework assignments.

**Shifts in theme: from content to didactics**

There usually also was a shift in theme in each meeting, which at first again occurred rather accidentally but, after I had noticed it in earlier meetings, was planned more consciously in later meetings. I would characterize the shift as one from content to didactics. Let me again try to illustrate this at the meeting in which the two units were compared. The question concerning the similarity between the two units can be said to deal with content, in the sense that its answer is that with respect to content the two units are essentially the same. On the basis of that answer, which as already noted the teacher had also given, our discussion gradually developed in a didactical direction in the sense that the structure of the content presentation was related to teaching and learning. To my question why the units begin with atomic models, the teacher's initial response was as follows.

This book simply assumes that... I later have to tell about those isotopes with which something special is up, so I first have to tell what isotopes are. [...] In order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you can't explain it. But you think it can be done differently?

The teacher's argument is of course valid within the existing structure of the units. But it was this structure that I wanted to bring up for discussion. I tried to do so by noting that beginning with atomic models is like beginning on the most advanced level. Is it not possible to already say something about radioactive phenomena without using particles, without immediately going deeply into the theory behind them? This at least made the teacher understand that I wanted something that differed from the existing structure.

You don't want to begin with... straight to the smallest particle and everything is connected to those smallest particles. You want to begin with... what does happen, how could that be, search... arouse interest... and first spend some time on that before we go more deeply into it, right?

I then tried to link up with his 'to arouse interest' in the sense of 'to induce a need for a deeper explanation,' an explanation at any rate of something they already know at a phenomenological level. The teacher put this in his own words as follows:

Would they be more inquisitive, that really is... more eager to learn about the particle model if they are going to hear about it later? First, what is it and what do we notice of it and effects, slowly settling in, and only then the explanations.

This 'to make pupils eager to learn about something,' which fitted into my developing ideas about a problem-posing approach, is a didactical theme that often recurred in our subsequent meetings.

Another more didactical theme that the teacher had picked up from this meeting is the following: is one thing really needed as a preparation for something else? This turned out when several meetings later he came back on his earlier statement that "in order to teach
the concept 'isotope' they first have to know something about atomic models, otherwise you cannot explain it," and concluded that it is possible to talk about isotopes without first having to talk about atomic models, which was in fact his first step in loosening himself from the existing structure. His reasoning was that all that is really needed to understand the concept of isotopes is the idea of slightly different things. He used the example of a bag of a hundred white marbles, of which on closer observation it turns out that one has a little crack and one a little black spot. By calling the three possibilities (perfect white marble, marble with little crack, marble with little black spot) three isotopes of white marbles, pupils could thus get the idea of what an isotope is without having to know anything about atomic models. He went on by noting that also in a subsequent treatment of atomic isotopes, there really would be no need to talk about protons, electrons or differing numbers of neutrons. All that needs to be said is that some atomic isotopes are different in the sense that something special can happen to them. I then elaborated on the theme the teacher brought forward, for I believed that he was very close to noticing that it is possible to talk about 'the something special that can happen to them' in other terms than changes in microscopic structure. I tried to do so by admitting his conclusion that it is possible to talk about isotopes without having to talk about atomic models, and by going one step further: is it also possible to talk about radioactivity without having to talk about isotopes? The teacher thus came to the insight that it is possible by simply calling something radioactive if a Geiger counter starts ticking in its vicinity. I could then also inform the teacher that I had this possibility in mind as a means to start up the series of lessons we were going to devise.

The didactical theme brought up here by the teacher also came back in later meetings. When later on we e.g. discussed the general constraints on the series of lessons we were going to devise, it returned in the following form: an activity should be meaningfully prepared by preceding ones and meaningfully prepare following ones.

When thinking about a suitable order in the themes I wanted to bring up for discussion, I also tried to make use of the idea 'making someone eager to learn about something.' That is, I tried to arouse the teacher's interest in a new theme on the basis of previous themes. In some cases I succeeded in this. The teacher for example understood why on the basis of the meeting in which the two units were discussed, I gave him the homework assignment to study some interviews in which pupils were prompted to give particle explanations.

You want to get rid of that particle model in your new planning. [...] We teach them that all right, those particles and how all of that... but can they themselves handle that too? For, of course, if you find out, they cannot handle that at all and haven't formed any idea at all of... then you will be on strong ground in saying we have to try it in a different way.

When shifting to a didactical theme I often used such concrete examples from our own meetings as a means to bring it up for discussion. If possible I would, for the same purpose, also use concrete examples from the lessons I visited.

Apart from shifts from content to didactics within one meeting, in retrospect I notice a similar shift in the course of the meetings as well. In later meetings we more often and
more directly discussed didactical themes, e.g.: pupils enter the classroom as empty vessels versus pupils have a background and this background influences their participation; explaining versus challenging pupils to find things out by themselves (as a form of making them eager to learn about something); asking pupils questions versus making pupils ask questions (as a form of making them eager to learn about something).

In discussing such themes, the teacher was of course especially interested in the consequences for his own role in the classroom. In fact, our discussion about his role was one an ongoing one. It continued during the following construction, try-out, reconstruction, etc of the didactical structure (cf section 10.4). In the preparatory period we often talked about the teacher's role in relation to yet another didactical theme: holding back versus steering. We tried to sort of take stock of the various ways in which these terms might be given content, if possible by using concrete examples. Steering or helping pupils, for instance, need not only consist in explaining. Pupils might e.g. also be helped in their learning process by making them arrive at some problem that they themselves come to see as worthwhile to work on. 'Holding back,' on the other hand, is not meant as 'withdrawing' or 'laisser faire.' It might e.g. be given content in the form of 'getting into the skin of the pupils' and 'trying to learn along with the pupils.' Since the preparatory period was also meant as a preparation for the coming construction of a series of lessons, in the later meetings we more and more began to talk about that as well (as part of our shift towards more didactical themes). In that context it was concluded that a substantial steering role should also emanate from the design of the series of lessons. In the construction of the series of lessons, we would have to think out such tasks and such an order in tasks that we have all reason to expect that by working on them pupils are steered in the direction of some goal (e.g.: their recognition of some problem). 'Holding back' might in that context be given content as sort of opposite to 'seeking confirmation of our expectations' or 'pursuing our goals at all cost.' Whereas the latter two attitudes do not prepare the ground for a meaningful evaluation, holding back in the sense of trying to learn along with the pupils may bring to the fore both the need for adjustments concerning (the order in) tasks, expectations and/or goals, and suggestions for plausible such adjustments (cf section 7.4.3).

Use of visits to lessons

One aim of the preparatory period was to familiarize myself with the teacher's classroom behaviour, i.e., in the terminology of section 10.2, both with his methodological and his interpersonal teaching style. In this respect my regular visits to his lessons were of course useful. They were also of use for our meetings, however, as I now try to illustrate. Let me first of all repeat that in our meetings we mainly focused on the methodological aspect. The interpersonal aspect of classroom behaviour, and in particular the teacher's interpersonal teaching style hardly came up in our talks. In the first place I did (and do) not feel competent to discuss the latter aspect. Secondly, it seemed to me that in his case there was hardly any reason to discuss it (cf section 10.2). So concerning this aspect I limited myself to occasional remarks how well I thought he managed to create and maintain a pleasant and productive working atmosphere.
Especially during our first meetings, I tried to bring forward some features of his methodological teaching style that I had picked up from visiting his lessons. He e.g. hardly ever gave a direct answer to pupils' questions, but instead tried to challenge them to themselves find the answer, if necessary by giving some casual clues: 'I don't know, but might it be that...' He would then some time later come back to see how they were doing and, if necessary, help them yet another bit further. Out of examples such as these, and the teacher's comments on them, eventually grew didactical themes such as: explaining versus challenging pupils to find things out by themselves; asking pupils questions versus making pupils ask questions; holding back versus steering.

In the above I have already repeatedly mentioned this aspect of the use of my visits of lessons, i.e., to have available concrete examples that both of us witnessed. Those examples could then e.g. be used to make explicit each other's approach, to start a discussion about further or similar experiences, to bring up or illustrate other didactical themes, etc.

Another aspect of the use of my visits of lessons derives from the different approaches of the teacher and me. One of my aims of our discussion of some interviews in which it was tried to make pupils give particle explanations, for instance, was to explore why pupils failed to do so, and this aim reflects my more theoretical emphasis. The teacher's more practical and pragmatic approach, with an immediate link to his everyday teaching practice, is e.g. reflected by the fact that following our discussion he wanted to find out about his pupils' ability to give particle explanations. Moreover, and in this sense my visits, and particularly the ones at the beginning of the preparatory period, provided a stimulus for him to try things out in my presence, so that we could later talk about it. Later on, however, he no longer needed my actual presence in order to try things out. It was then rather his own enthusiasm that made him do it. Of course, he would then still report about his experiences in a subsequent meeting.

Some learning outcomes

In his review of the meetings, the teacher indicated what he had learned from them:

Well, one of the things that have most struck me is that much more than before I wonder whether my way of teaching, treating the subject matter, observing and evaluating pupils... is done in the right way. Less than before I rely the old routine in which, as I have come to realize, I was somewhat getting stuck. So you could now describe it as greasing the whole thing in order to counter the getting stuck.

Also during the meetings themselves he had already made similar remarks, e.g.:

...you are confronted with what you are really doing the whole day, and self-evidently so.

So you see, not just here I am wondering... but also during my lessons I am... it already is on my mind. Well, why am I doing this? I do not wonder whether I am doing it right, really, but could I do it differently, does it make sense that I tell it to them, what do they really pick up from it, what will they do with it?

So the teacher has experienced the meetings as useful, as refreshers of his teaching practice in general. This may also be illustrated by the enthusiasm with which he tried things out that were discussed in meetings.
More in particular, the teacher has also experienced the meetings as useful. Concerning the themes relating to content, for instance, he indicated to have become sensitive to the problems that pupils have with particles and to the question whether a treatment of the topic of radioactivity should be based on particle models. He in fact admitted to have been shocked by the poor understanding that pupils have of particle models. And his pupils too, as he found out when in one of his classes he challenged the pupils to explain why a roadway expands on a hot day and they came up with answers such as: the molecules expand, the air between the molecules expands, or the intermolecular spaces between the molecules expand. Here is one more example of the influence that in this respect the meetings have had on his teaching practice:

Today, for instance. [...] Someone drops the word 'molecule.' Another one immediately says: the smallest particle of a substance with all its properties. Never ever would I have reacted to that. That is correct. Today we have talked about it for a quarter of an hour. Have talked about it for a quarter of an hour! Would it really be like that? [...] I don't know whether those pupils have gained anything from it. But at any rate it is the result of these meetings.

Concerning the didactical themes, the teacher wrote in his review that especially our recurring discussions about 'holding back and steering' had been very instructive. He also indicated to have gathered from the totality of our meetings that I am a proponent of "letting pupils themselves experience, describe and tentatively process, instead of the traditional model of learning, digesting and testing." In this respect too the teacher noted that the meetings have had their influence on his teaching practice, e.g.:

...I more often try to get into the skin of the pupils...

It has already yielded fruit (still to be seen whether it is ripe) in my daily teaching practice. Holding back, listening to pupils, adjusting a little later. A changed attitude with regards to pupils' making notes of observations. Less direct 'explaining.'

The main thing I learned from the meetings was to further specify and illustrate what the consequences for the teacher's role are of my ideas about how pupils could meaningfully learn about the topic of radioactivity. For up to then those ideas mainly concerned pupils' learning process, e.g.: whether for pupils one thing (e.g. particle models) really is a meaningful preparation for another thing (radioactive phenomena). Of course I had some ideas about the teacher's role in pupils' learning process, but it was the teacher, with his pragmatic demand for immediate applicability to his practice, who continuously challenged me to do further develop those ideas and also contributed to that further development. For me too, our discussions about 'holding back and steering,' and particularly about how the notions 'holding back' and 'steering' could be given further content in relation to my developing ideas about a problem-posing approach, were most instructive.

Another thing I learned from the way the meetings themselves proceeded, was how useful it is to regularly and explicitly build in reflective activities. For it had been beneficial for our meetings that each of us regularly thought about, and that we then explicitly talked about, questions such as: what have we done, what have we achieved and where does that leave us? So it would also be useful, and moreover in line with a
problem-posing approach, to build in such activities in the series of lessons we were going to devise.

Some of the minor, but still important, things I learned also relates to the construction of the series of lessons. The textbook that pupils are to work with should be carefully edited, and easily surveyable and readable. It should be clear to them that quite some time and effort has been put in it, in order to increase their willingness to seriously work with it. The latter point may be compared to a remark that the teacher made in his review, namely that it was also due to my careful preparation of the meetings that he was challenged to invest quite some time in the homework assignments.

I conclude that our preparatory period had met most of its aims. I had come to familiarize myself with his way of teaching. He had become sensitive to the problems with the existing structure to treat the topic of radioactivity, and had gathered some ideas about an alternative structure. We had developed a common way of talking about teaching and learning that promised to be useful for a productive future working relation with respect to writing, trying, etc new teaching materials. Particularly the theme 'holding back versus steering' seemed to be useful for both of us. For the teacher because it directly concerned his role; for me to further think through what, in terms of holding back and steering, the consequences for this role are in a problem-posing approach. I felt prepared for our future cooperation, and so did the teacher: "I'm one hundred per cent behind the experiment. I have confidence in it."

What had not become clear, as the teacher remarked in his review, is "what precisely the lines are along which and why your research takes place." I guess I myself also did not know that at the time.

10.4 Cooperation during the (re)construction and try-out of the didactical structure

Following the preparatory period, the teacher participated in my research for a period of two and a half years. In this period he worked with both versions of the didactical structure and was also involved in the construction and evaluation of them. In this section I describe some aspects of our cooperation in this period, and in particular how in this period our discussion about his own role in the classroom continued, with the eventual aim that he made himself so familiar with the essence of (especially the second version of) the didactical structure and his role in it that he would not deviate essentially from it.

10.4.1 Construction and try-out of the first version

For the construction of the first version of the didactical structure there was about three months available. In these three months I had to put flesh to my still vague ideas about another way to structure the treatment of the topic of radioactivity (e.g.: not begin with particles but rather end with them), by thinking of suitable tasks and a suitable order in the tasks. Choices had to be made (sometimes rather ad hoc) in order to meet some constraints: the total series should take about 10 lessons (of 50 minutes), applications of
radioactivity should be treated, the examination syllabus had to be covered, etc. Furthermore, a textbook for pupils had to be written, edited and laid out in such a way that for them it would be challenging to work with, and easily readable and surveyable. At the end of the three months there was indeed a pupils' textbook but, as it had been produced under heavy time-pressure, I was not quite satisfied about it. I did have the feeling, however, that it was worth being tried in the sense that from the try-out we could learn a lot about possible improvements.

In those three months the teacher was one of the people who commented on my intermediate products, and what occupied him most was to see how the vague ideas about an alternative structure that we had talked about during the preparatory period gradually assumed a more definite and concrete form. There simply was no time left to discuss his role in relation to the material that was being written any further than whether he thought it feasible to do the activities in the time that was planned for them. Moreover, the teacher guide that was also being written, was more a justification of the new structure of the treatment of the topic of radioactivity than a practical guide. So also concerning the teacher's role I had the idea that a lot could be learned from the try-out. It was in the evaluation of the first version of the didactical structure that the main work had to be done, with respect to both the structure itself and the teacher's role in it.

The first version of the didactical structure was tried in two classes. The procedure of the class observations had been much the same as later in the try-out of the second version (cf section 9.2.1). In one of the classes the lessons were recorded on audiotape, in the other on videotape; on the basis of the experiences in the class in which a particular lesson was given first, some changes were sometimes made concerning the matching lesson in the other class, etc. But whereas the procedure of the observations was similar, the first impressions from the observations differed markedly. For, in line with the above mentioned expectations, the first impressions I gathered during the try-out of the first version the didactical structure were that it certainly was not yet 'good enough.' That is, too often the things the pupils did and said were too far out of line with what they were expected to say and do. Moreover, whereas in some cases rather cosmetic changes might suffice to improve matters (e.g. by avoiding unspecific terms in the formulations of the tasks, cf section 7.4.1), in others more structural improvements seemed necessary. In order that pupils perceive the coherence in successive tasks (cf section 7.4.2) or come to appreciate some problem in the right way (cf section 7.4.3), for instance, it seemed necessary to not just superficially change some tasks but also to change their function and aim, and the way in which they are to be put in a coherent structure.

After the try-out of the first version the teacher was asked to write down his first impressions. The following may give an idea of what they were.

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After the try-out of the first version the teacher was asked to write down his first impressions. The following may give an idea of what they were.

The last weeks before the start of the series of lessons were marked by a lot of pressure, concerning the normal work at school as well as the preparation of the start. [...] In addition to this the material still had not got its definite form and a remark of [one of the other people who commented on the material] about the amount of subject matter and the in his opinion too optimistic planning had made me doubt about the possibilities of the material. After in the end the material had got its definite and carefully edited
form my concerns were somewhat taken away again. Once the lessons had begun I was glad to have the opportunity to always teach the lesson once again in the other class in order to then deal with problems that had been found in the first lesson. Because of that it turned out that after four lessons I myself got the feeling that the planning was feasible and my decreasing tension for the lessons of course made that the further lessons proceeded less tensely.

10.4.2 Evaluation of the first version and construction of the second version

The above may already indicate that at the beginning of the evaluation the teacher and I had a different attitude, which may again be characterized as the difference between a theoretical and a pragmatic attitude. For me the real work still had to begin, and I was sure that the evaluation would lead to suggestions for structural changes, for substantial changes in the didactical structure itself. For the teacher, however, things had worked out well, and by this he meant things like: we made it in time, the pupils learned something and they were involved.

In the first stages of the evaluation this difference was not properly taken into account, however. We had weekly sessions, for which we prepared by studying one lesson. The teacher studied the videotape of that lesson, i.e., the lesson in one of the classes. I studied the videotape too (together with Hans Créton and Wout Moerman), and also the audiotape of that lesson (i.e., the lesson in the other class) and pupils' notes. During the session we then exchanged our findings. At least, that was the plan. It turned out, however, that there was hardly any exchange, but rather a one-way transmission from me to the teacher, in which I pointed at numerous cases in which what the pupils did and said was (far) out of line with what we had expected, at cases in which the teacher's role could have been better, at possible suggestions for improvements in the didactical structure itself and the teacher's role in it. I was far from content about this one-way traffic. The teacher, on the other hand, felt sort of guilty for not having enough critical remarks. So the sessions were increasingly dissatisfying for both of us.

In order to escape this situation, we spend a session on the sessions themselves. Below are some fragments of what the teacher then brought forward, which also illustrate our different attitudes.

I've looked quite differently at [the lessons]. I think: I have my material, I give my lessons, well, I think that my pupils have learned something of it, right. You've looked quite differently at it, because your starting point was: well, we'll see whether the pupils have learned something of it. Well, I don't look that way at lessons, I don't look months back. I think: well, the lessons are over, we have made it in time, so I was satisfied, right. So I thought that the lessons went well. If you're looking at it through such a magnifying-glass, well, then indeed you're going to say, and I really do admit that now too: what we had expected did not quite come out and it might have been done differently.

[During the try-out] I myself didn't have the idea that we were going to discuss it that well, that accurate, that we'd go that deeply into it. So I really am content about the sessions, about the way we're working on it, but it is different from what I had imagined. Much more about small things, of which you say: here, see that, now? [...] I found it for instance nice... a nice example, that that second
lesson I had watched, that I had hardly made any notes really and that I tell you those
and that you then come with [...] no less than thirty remarks, well, five pages full. And if
I read them over, then I think: and it is like that too. Well, and that you pull them out
much more easily than I do. I obviously take notice of quite different things: whether
the children are participating, or that they... I don't take notice of whether they... And I
do think along with you whether it can be done differently, but I do not pick it out
myself.

We concluded that it had been a kind of strange experience for the teacher to look
through a magnifying-glass at the small things of something that was well over and that
on the whole he was quite satisfied about. On the other hand, now that he got used to the
idea he also appreciated that by looking this way it became clear that what we had
expected did not always come out and that things might have been done differently. In
fact, the teacher also indicated that through the evaluations he had become aware that
during the try-out he had not grasped the point of some activities, which accordingly he
had not carried out very well, and had also become aware of other cases in which his role
had not been adequate. Furthermore, the teacher indicated that the many small things
added up to suggestions for quite structural changes, which he appreciated as improve-
ments: "It is a whole different approach, it is quite a different approach. I do think so. The
new design appeals to me."

So the main source of the problem seemed to us that, although he did think along with me
and appreciated the points I brought forward, the teacher himself did not pick out the
things that I did and did not himself come up with suggestions for structural changes. It
was not so much problematic that I picked out more things and that I came up with the
suggestions for improvements. After all, I had given the didactical structure a lot more
thought than the teacher had. Moreover, it was precisely in this period that things began
to fall in place for me, that I began to arrive at the global outline for a didactical structure
as outlined in chapter 6. So it was quite naturally that I took the lead concerning the
structural aspects. What was problematic, however, was that in the sessions up to then
this inequality had not been properly taken into account. For the teacher had the same
general assignment that I had: study a lesson and comment on it.

As a solution to the problem we suggested that each of us would study the lessons with
a special assignment. I would especially focus on the structural aspects, e.g.: whether the
things pupils do and say is in line with what they were expected to say and do; whether
by changes in formulation, aim, function, order, etc pupils might come to perceive the
coherence in successive tasks or come to appreciate some problem in the right way, etc.
The teacher, on the other hand, would especially focus on, what we called, the procedural
aspects, e.g.: whether the way in which an activity was carried out has contributed to
reaching the aim of the activity; whether by changes in instructional technique or teacher
participation (more) pupils might come to (better) appreciate some problem in the right
way, etc. Of course the structural and procedural aspects hang closely together. So the
teacher had to keep on thinking along with me with respect to the structural aspects,
though he was no longer expected to make substantial contributions concerning them.
And of course I had to discuss the procedural aspects with him, and in particular their
relation to the structural aspects.
It turned out that by the above division of tasks the problem was indeed solved. Firstly, it made more clear that both concerning the structural and the procedural aspects the series of lessons needed to be considerably improved, and also which were the structural and which the procedural improvements. Secondly, the teacher's new task was directly related to what most concerned him: his own role, and he was willing, and able, to work on his new task. Thirdly, the new task was a good preparation for his task during the writing stage of the second version of the didactical structure, namely to write his own guide. His new task, finally, enabled us to continue our discussion about his own role in the classroom, which in the preparatory period we had already begun, and this time more concretely in close relation to the didactical structure.

So the teacher began to study the tapes again, this time especially focusing on the procedural aspects. In the terms of our theme 'holding back versus steering,' he noticed that there were many cases in which his participation had been far too steering. There were cases in which he virtually took over an experiment that pupils were performing, put words in their mouths, heard and saw much more in what pupils said and did than what they actually intended to say and do (cf section 7.4.3), was too focused on pulling out the desired answer (as in: "I've already heard the right answer"), he tended to address himself to especially the 'better' pupils, etc.

Obviously we did not discuss such cases in a blame-context, but acknowledged that a lot of them derived from the fact that the whole thing had been new and stressing for the teacher. He had been nervous, especially during the first lessons (cf his review of the try-out). He had felt the responsibility to make it happen as expected, and therefore was very much focused on the desired answers, apt to hear and see more than there was to see and hear, etc. He also had his initial doubts about the possibilities of the material, whether the pupils are indeed able to find things out for themselves or in the time planned for it, and therefore he had sometimes tried to speed things up by putting the words in pupils' mouths, taking over experiments, addressing himself especially to the better pupils, etc. Furthermore, sometimes our expectations had simply been too high, so that on the spot the teacher had to deal with unexpected situations. I also think that keeping a tight control with respect to content was an ingredient of his way of keeping order.

In our discussions I rather tried to make the teacher take two steps. First, to gain confidence both in the material and in the pupils. That is, the tasks, certainly when the suggestions for structural improvements are taken into account, are such that the pupils are indeed able to take control over their progress with respect to content, that also without a tight control of him in that respect they are willing and able to themselves think of experiments, carry those out, draw conclusions, formulate questions, etc. So with respect to content the steering part of the process should be initiated by the material and further driven by the pupils as they work with the material. The second step relates to the procedural aspects: to find ways to so guide the process that, on the one hand, all pupils are involved, make contributions, listen to each other, etc while, on the other, the process still proceeds orderly and structured.
In the first step we discussed cases in which, as the teacher himself had already noticed, his participation had been far too steering, and compared those to cases in which he had appropriately held back. Sometimes it was even possible to make this comparison with respect to the way that one particular activity was carried out in the two classes. This was the case, for instance, concerning the task whether or not the cleaners of an X-ray department need lead aprons. In the one class pupils were divided over the matter. The teacher subsequently gave both sides the opportunity to convince each other, an activity that he ingeniously managed by imposing the rules that the two sides have to take turns in bringing forward a point, that someone who wants to bring forward a point for his or her side has to stand up and that only someone who is standing up is allowed to speak, and that pupils are allowed to switch sides each time one side has made a point. Since neither of the sides turned out to be able to make a convincing case, the pupils were then asked to think of an experiment that could be done with the material present in the classroom and that might decide the issue. The pupils proposed to put the X-ray machine on for a while and then measure whether its walls had become radioactive. The final conclusion, on which everybody agreed, was that lead aprons are not necessary. In the other class, however, things went rather differently. There all of the pupils initially agreed that lead aprons are needed. This unexpected result (he had expected that, as in the other class, the pupils would be divided over the matter) so unnerved the teacher, that he completely took over from then. He forgot to let the pupils think of an experiment that would prove them right. Instead he called a pupil forward, told him to put the X-ray machine on for a while, to then measure the walls with a Geiger counter, and concluded that lead aprons are not necessary. This conclusion lead to quite some protests from the pupils, probably because they did not have the faintest idea why the experiment had been carried out. They certainly had not decided for themselves that it is an experiment by means of which it can be decided whether or not lead aprons are needed. Consequently, the experiment played no role in their further reasoning. What had become clear to the pupils, however, is that the teacher had launched an offensive at their communally held opinion that lead aprons are not needed, and they began to passionately defend that opinion, e.g.: dust particles or the air in the X-ray department have been irradiated and therefore are radioactive. The experiment also played no role in the teacher's further reasoning. Instead he tried to explain why e.g. dust particles cannot have become radioactive, pretty soon got stuck in the explanation when he noticed that in it he would have to use the not yet settled concepts of irradiation and contamination, and ultimately saw no other possibility than to force the matter: as you will learn in the next chapter, irradiated dust particles are not radioactive. At that stage it had of course become clear to the pupils that the teacher very much wanted them to say that lead aprons are not necessary. So in the end they decided to meet the teacher, at least part of the way: okay, the cleaners do not need lead aprons, but they do need something else. So here we had a case where the teacher's very steering role had rather been detrimental to pupils' learning process. If the teacher had given the pupils the opportunity to themselves steer their learning process (by letting them, as the pupils in the other class, think of an appropriate experiment), then they would have been

4. In the second version of the didactical structure this task returned (cf section 8.4.2), but, due to some structural changes, at a different place.
confronted with experimental facts that, for good reasons, they themselves had brought forward. The further discussion could then have been based on facts (on what is seen and heard) instead of vague speculations and not yet justified conclusions, and would then not have proceeded in an undesirable attack-and-defence context.

In the second step, the teacher thought of ways to so structure the classroom process that as much pupils as possible are given ample chance to take control over their progress with respect to content: in which cases group work is most appropriate and how it could best be organized; in which cases a class discussion is most appropriate and how it could best be initiated, guided, rounded off, etc. It was of course clear to the teacher that giving the pupils control over their learning process does not imply his withdrawal, especially not if the process is still to proceed orderly and structured. On the contrary, it requires him to draw on a whole repertory of management techniques. So the teacher studied which such techniques he had already spontaneously used (in the above I have given an example), how they had worked out, where else they could be applied, and he explicitly thought of other techniques. As it was part of his way of keeping order, for instance, to be very much present and in particular to be speaking quite a lot, we thought of a way to combine this with not taking over with respect to content, e.g.: when pupils were carrying out an experiment he could physically withdraw, but verbally be very present as a kind of commentator.

As my evaluation of the first version, via ever more concrete suggestions for structural improvements, gradually transformed into the construction of the second version, so the teacher’s second step gradually transformed into writing his own guide for the second version, i.e., into a detailed specification of the instructional techniques and his role in the activities that were planned in the second version. This guide was indeed very much geared to the teacher himself, and contained all sorts of reminders that especially concerned him, e.g.: do not yet go into it; aim at mutual agreement; do not take over!; try to involve especially the ’lesser’ pupils in the discussion; do not run ahead of things; take stock of all suggestions and solutions. Writing his guide was at the same time the teacher’s preparation for the try-out of the second version.

10.4.3 Try-out and evaluation of the second version
At the start of the try-out of the second version of the didactical structure, both the teacher and I had quite some confidence in it, i.e., we both expected that it would come out as ‘good enough.’ Both of us also expected that the teacher had made himself so familiar with the essence and details of it and had so well prepared his role in it, that he could carry it out as intended. In chapter 9 I have already tried to show that both expectations came true, although some structural as well as procedural modifications were still necessary (see e.g. section 9.4.1). I also refer to chapter 9 for a description of the cooperation between the teacher and me during the try-out and evaluation of the second version.

After the evaluation, the teacher has written a draft teacher guide that is no longer meant to be especially geared to him. It can be characterized as a shortened and more easily readable merger of (parts of) chapters 8 and 9 of this thesis, i.e., a justification of
the main tasks, augmented by pupils’ reactions to them and some practical clues for teachers. Out of this draft teacher guide I now quote some fragments of the closing section in which the teacher himself gives a general evaluation of the material.

Once I described the material as ‘the engine,’ the ‘fuel’ for which is represented by pupils’ contributions. Now that I’ve worked for several years with this material, I’ve discovered that this metaphor is not that badly chosen at all. The pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions. And even to the extent that the engine always got that well run in that almost as a matter of course it made its way through the topic of radioactivity. [...] Apart from that all, I in fairness have to tell that teaching in this way, with ‘holding back’ and ‘listening,’ does require quite an effort. After these lessons I generally was more tired than after lessons taught in my old way. The question then presents itself whether that additional effort balances the achieved result. I do give this question a cautious ‘yes,’ though. The design of the material (its structure, emphases and basic assumptions) has more appeal to me than the traditional treatment of the topic of radioactivity. Furthermore it is my experience that practically throughout the series of lessons the pupils enthusiastically continue to take part. In evaluations of the unit the pupils themselves too indicate that they have experienced ‘learning from each other’ and ‘having come to solutions oneself’ as positive [cf section 9.6, KK]. [...] I have confidence in the strategy described in this guide. You too will have to get confidence in it. All I can say is that in my series of lessons on the basis of this material [...], the necessary fuel for the engine has always been sufficiently supplied by the pupils. To put it differently: I’ve never been afraid that we would come to run dry; we’ve never even driven on the reserve tank.

10.5 Some general remarks on the role of a teacher

In this section I try to go beyond the educational experiment that this thesis reports on, i.e., beyond this particular teacher that has worked with this particular material in this particular research. In doing so I also go beyond a firm ground of experiences to base my opinions on and, to some extent, beyond my competence. So this section is of a speculative nature and should accordingly be read as a representation of some of my personal ideas. Let me begin with going beyond this particular topic. This is what the teacher has to say about it (in his draft teacher guide).

My most important finding, though, is that you will not be able to work with this material if you haven’t at least come to believe in its basic assumptions, e.g., confidence in the importance of ‘postponing questions’ and ‘holding back’ of you as teacher. Are these basic assumptions and strategy also applicable to other topics from the physics curriculum? I do think so: postponing questions will be going to function as something normal for the pupils. Especially if more often they notice that the answers are found (and often by themselves) as a matter of course. [...] Thinking of experiments oneself and drawing conclusions from those is, according to me, also of use for more topics. Does all this mean that in your physics classes you will tomorrow be able to begin with ‘holding back,’ postponing questions, letting pupils themselves think of experiments, carry those out and note down conclusions? The answer to this question is a very distinct: no! Material that makes possible such an approach for other topics simply isn’t
available. But if such material is to come, and it isn't up to me to take care of that, I will surely use it.

Like the teacher, I believe that the basic assumptions and strategy are applicable to other topics as well. In fact, in chapter 6 I have already quite generally presented a global outline of a didactical structure. I also think that the teacher will be able to work with material that, for some other topic, makes possible a similar approach, i.e., with a 'good enough' didactical structure of some other topic. I also think that it would not take him that much preparation time as his learning to work with the didactical structure of the topic of radioactivity has taken him. After all, he does already believe in the basic assumptions and strategy, so his preparation would simply be a matter of finding out how the basic assumptions have been detailed and how the strategy could be detailed for the case at hand. In all this, he would of course draw on his experience with (working with) the didactical structure of the topic of radioactivity. I also think that the teacher himself would not be able to construct, for some other topic, material that makes a similar approach possible. This, of course, is no disgrace. I myself, for instance, think that I am able to construct didactical structures for other topics, and that those (re)constructions will much quicker converge to 'good enough' didactical structures than has been the case for the topic of radioactivity, but I do not think of myself as good enough a teacher to be able to work with such didactical structures without any further training. But, as I have already noted, all this is speculation.

Let me speculate a bit further and ask whether other teachers than the one who participated in my research are able to work with the 'good enough' didactical structure of the topic of radioactivity (or some other 'good enough' didactical structure), and what it takes to make them able to do so. One thing that it takes, as the teacher who participated has repeatedly emphasized, is confidence in its basic assumptions and strategy on the one hand, and in the pupils on the other. In order that other teachers gain such confidence, I do not think it is necessary that they go through the whole process that the teacher who participated has gone through (and that has been the main topic of this chapter). Neither do I think that it will be necessary that they study the theoretical background, i.e., something like chapter 4 of this thesis. What I think might be useful is that they actually have lessons that are based on the 'good enough' didactical structure at hand and that they watch videos of (fragments of) lessons in an actual classroom. As a pupil and an observer they will thus, as it were in play, get acquainted with why and how the didactical structure is as it is. What they will have to gain confidence from, I guess, is that they see it working, that they also are impressed by the fact that "[t]he pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions." I do not know whether this kind of in-service training will work. We have not (yet) got any experience with it. The teacher and I have run a couple of workshops at a teacher conference, however, in which we, be it in a time span of just one and a half hours, tried to do the sort of things just mentioned. And the fact that most teachers present at our workshops were quite enthusiastic about it, is an argument in favour of attempting an in-service training along the sketched lines.

However, having gained confidence in its basic assumptions and strategy is one thing,
being able to work with a 'good enough' didactical structure quite another. It requires, for instance, that one can rather flexibly draw on a quite extensive repertory of management techniques. In the terms of Brekelmans (cf section 10.2), I would without any reservations advise only teachers with an 'authoritative' or 'tolerant and authoritative' communication style to work with a 'good enough' didactical structure. They seem to be the best teachers anyhow, no matter what instructional methods they use. Whether, and how, someone (e.g. a student teacher) can acquire the sort of desired management techniques or communication style is beyond my competence. I do think, however, that such an acquisition will involve the abandonment of some of the common ways in which (student) teachers (learn to) structure lessons, often as a means to keep order. This was once more brought to my attention by Marjolein Vollebregt, a PhD-student who, concerning her first attempts to write a didactical structure (for the introduction of particles, see e.g. 1994), had written in the diary she keeps: "I still don't succeed in writing a scenario that starts from the pupils. Too strongly I hold on to the activities and aims with respect to content in order to maintain with those the common control of the teacher." In a verbal explanation she said that as a student teacher she had learned to structure her lessons as follows: set your goals, i.e., what pupils should be able to do at the end of the lesson; think of activities that are needed to achieve that; think of ways to control that the activities are indeed carried out as desired. So she had learned to think about the appropriateness of activities from the point of view of the teacher's aims and not from the point of view of pupils' motives. And she had learned to keep a tight control with respect to content, especially as a means to keep order, i.e., as a means to survive in the classroom. Now, of course, I also want student teachers to survive, but I wonder whether for that purpose it is necessary that they learn to structure their lessons and to keep order as indicated above. Are there no other ways that are still within the reach of student teachers? It seems to me that such questions concerning the interconnection between the methodological and the interpersonal aspects of teacher behaviour deserve a thorough investigation.

10 The teacher's role

10.1 Introduction

In the preceding I have repeatedly pointed at (the importance of) the role of the teacher. In chapter 8 I have noted that the teacher's role in working with a didactical structure as the one outlined there is different from the teacher's role in more traditional approaches. For example, giving pupils more control over, and thus more responsibility for, their

5. Quoted with approval.
progress with respect to content implies a shift in the teacher's control and responsibility: a shift towards procedural control and responsibility for managing the process. In section 7.4.3 I have noted that it also involves a shift from wanting to make pupils say and do particular things (with the associated danger of ‘hearing and seeing much more’ in what the pupils say and do), towards the teacher's being more prepared to find out what the pupils actually do say, believe, want, etc and to (re)determine his or her goals on the basis of what they actually say, believe, want, etc. In section 7.3 I have noted that even if a didactical structure as such can be judged as ‘good enough,’ which is the maximum attainable, it still needs the creativity of a good teacher for it to lead to successful education.

In section 7.3 I have also noted that at least the evaluation of a didactical structure should take place in cooperation with the teacher that has worked with it. In section 9.2.1 I have mentioned that I cooperated quite closely and intensively with one teacher. He not only worked with the second version of the didactical structure outlined in chapter 8, but had also worked with the first version, and was involved in the construction and evaluation of both versions. By this cooperation it was tried to secure as well as possible that the teacher had made himself so familiar with the essence of the didactical structure and his role in it that he would not deviate essentially from it.

In this chapter I somewhat elaborate the above themes. But I now first briefly report on some experiences during the first year of my research, which have made me realize that a cooperation with a teacher should be very carefully set up and that it should be set up with a teacher that has good managing qualities.

In the first year of my research I observed two series of lessons in middle ability classes that used the unit *Radiation, you cannot evade it...* (Knoester & Lancel, 1988; cf section 3.3 for some findings of the observations). One of these series was taught by a teacher that possibly was to further participate in my research, and the main aim of my observation of the series of lessons taught by her was to find out whether there was a basis for further cooperation. Before the series of lessons I told her my at that time still very vague ideas about the aim and nature of my research: I wanted the pupils to meaningfully learn about the topic of radioactivity, and for that purpose one should somehow start from pupils’ existing knowledge; I later was going to write a series of lessons on the topic myself, and to get some ideas for that I would like her to try out some additional activities while teaching the unit *Radiation, you cannot evade it...*. The teacher then indicated that she was somewhat sceptical about my aim. Her scepticism did not so much consist in a denial that pupils have ideas of their own, but rather in her experience that the gap between their own ideas and those of physics was rather large and hard to bridge. In fact, she indicated that in her worst moments she sometimes sighed that all that can be achieved is that pupils learn to solve standard exercises for examinations. Nevertheless, she said that she herself constantly tried to bridge the gap and so she was quite prepared to participate and to try my proposals. In fact, she already saw the unit *Radiation, you cannot evade it...*, of which she was one of the authors, as making a
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serious attempt to bridge the gap.\footnote{Because the unit is based on micro-level explanations (cf section 3.2), I myself could not see it that way.}

During the series of lessons her scepticism was not noticeable at all (at least not by me). She was enthusiastic, put quite a lot of time in it, tried to carry out my proposals for additional activities as well as possible, and regularly indicated to enjoy it all. I too was satisfied about the series of lessons in the sense that I was confirmed in my suspicion that the structure of the unit I was going to write myself had to be quite different from the structure of the unit \textit{Radiation, you cannot evade it}... Moreover, from how the tried out additional activities worked out I got some ideas about activities that might be useful for the unit I myself was going to write.\footnote{Some of the tried out additional activities are indeed precursors of activities that figure in the first and/or second version of the didactical structure.} There was also a source of trouble, however, relating to the teacher's order-keeping abilities. The situation in her classroom could most of the time best be described as a 'non-aggressive disorder' (cf Créton & Wubbels, 1984). She did not show much leadership, and quite often the lessons were poorly structured. She generally tolerated quite some disorder, and the pupils very often were not task-oriented. Although she was quite concerned about the class and willing to explain things over and over to pupils who had not been listening, the whole situation was usually so unstructured that only the pupils in her direct neighbourhood were attentive, while the others would do other things such as talk with each other or make some homework. They were not provocative, however, i.e., their other activities were not directed against her, and she usually ignored them while talking loudly to the pupils near her. Her few efforts to also involve the other pupils were usually delivered without emphasis and mostly had little or just a short-term effect. Though most of the pupils seemed to like her and she certainly liked most of the pupils and took a great deal of interest in them, the interaction between her and the pupils very often resulted in a non-productive equilibrium in which all of them sort of seemed to go their own way. The teacher's limitations especially came forward during the additional activities, most of which were of the 'class discussion'-type. For even though the teacher really attempted to involve all pupils, she mostly did not succeed. The result was that the discussion was also hard to follow for the few pupils that were attentive, because of the many times that it was interrupted by the teacher's (vain) attempts to call the other pupils to order. The teacher was well aware of all this, and although she herself also did not find her teaching style particularly good, she also maintained that, at least for the time being, it reflected her best way of surviving in the classroom. So if there was to be a further cooperation with this teacher, it would have to be accompanied by an in-service training in managing order problems.

However, and at the time quite unexpectedly for me, the teacher herself decided that there was not going to be a further cooperation. The results of the test that followed the series of lessons had reawoken her old scepticism. The test consisted for about two-third of rather standard tasks (about half-life, the different penetrating power of the different kinds of radiation, the number of protons, neutrons and electrons that a given isotope consists of, etc, i.e., exercises of the type that could come up in the examination), and for
about one-third of tasks that demanded some insight (in e.g. the point of distinguishing between contamination and irradiation). It turned out that generally the pupils answered the standard tasks sufficiently well, though not overwhelmingly so, but the insight-tasks rather poorly. I did not make much of those test results, or at any rate I found them quite understandable. For, as I have already noted, the additional activities, which explicitly aimed at insight, went past most pupils. Furthermore, the additional activities were not backed up by worksheets and also did not fit nicely into the unit *Radiation, you cannot evade it*.... For me, all this meant that adding just a few activities was not sufficient. Although some of them might be useful, they had to integrated in a structure that was quite different from the structure of the unit *Radiation, you cannot evade it*..., and had to backed up by written material that would serve as a hold for pupils. In short, I would have to write my own series of lessens and that was precisely what I was going to do. For the teacher, however, the results of the tests confirmed her earlier scepticism. Below I give some fragments of her verbal explanation of her decision to quit.

If I look at the enormous amount of time I have spent on it and that the part that does later come up for examination, that already that part is not really right, and that this [the part relating to insight, KK] apparently also has not got across, then I say... well, this is wrong, this is a waste of my time, period. These pupils [middle ability pupils, KK] have been taught tricks and memory aids from primary school on, otherwise they do not make it through that school. And then you cannot in six weeks all at once aim at insight... and forget that there is something like an examination waiting for them that they will have to do. So I think that in this context it is indeed unfeasible [to aim at insight, KK].

I have followed your road all along, and if I now look at what it has yielded then I think... well, if I had done it my way it would have taken me, a, less time and the test would have been made better. [...] Not the second part [the insight-tasks, KK], the multiple choice [the standard tasks, KK]. Then I would have shifted the emphasis. And then I think, simply from the point of view of my pupils, that is what they have to know. And then I will do my best to also bring in those other things, but already beforehand I accept that that will largely be a wasted effort. I told you so at the beginning: you can try it, but I don't think that it will work. And then I am working on it and then I am really enthusiastic and then... and I did terribly enjoy doing it, I would like to always work like this, but... well, I just notice that it has had little or no effect up to now.

I think we have done all that we could have done in this context [she later specifies this to: with these pupils, in these times, with this previous education; KK]. I would not know what else you should have done.

Whereas for me the whole thing still had to begin, for the teacher it was all over; whereas I thought the time was ripe to lay my own road, she thought she had already followed my road all along, and with little or no effect.

In order to find a new teacher some heads of physics were approached with the question whether they knew a good and experienced teacher that might be willing to participate in an educational experiment. In this process the teacher that I worked with for the rest of my research came forward. In section 10.2, this teacher is characterized. In order to carefully prepare a productive working relation, the teacher and I took quite some time to get acquainted. In section 10.3, I report on this preparatory period. In section 10.4, I go
into some aspects of our cooperation during the (re)construction of the didactical structure. In section 10.5, finally, I try to go beyond this one teacher and more generally address the question what it means for a teacher to work with a didactical structure that is 'good enough.'

10.2 Characterization of the teacher

The teacher I worked with was born in 1945. He graduated from a college of education in 1967, but only taught for about two months at a primary school. By means of some refresher courses he in 1969 acquired a qualification to teach physics and chemistry at the LBO and MAVO types of education and at the first three years of the HAVO and VWO types of education (cf section 9.2.1). From 1969 to 1984 he taught physics and chemistry at a school which consisted only of a MAVO-stream. In 1984 this school merged with another school to form a school for MAVO, HAVO and VWO. It is at this school that up to this day he has taught physics and chemistry at the levels he is qualified for. It is thus also the school at which he has worked with the various versions of the didactical structure. The above may suffice to illustrate that he is a very experienced teacher.

The head of physics that recommended him also assured us that he is a good teacher, i.e., a teacher of whom pupils say that he is a good teacher. I also got this impression by observing some of his lessons in the preparatory period (cf section 10.3). There was a pleasant and productive working atmosphere in his lessons, there were hardly any order problems and if some cropped up the teacher usually managed to immediately and effectively deal with them. I would have characterized him as 'strict, but nice' or 'nice, but strict.' In order to somewhat further substantiate these claims, the so called Questionnaire on Teacher Interaction (QTI) was administered to the teacher and several of his classes. The QTI, which was developed in the early eighties by Créton & Wubbels (1984), is an instrument to characterize the affective climate of the learning environment, as perceived by the participants (pupils and teacher). If we roughly discern two aspects of teacher behaviour, a methodological one that relates to content presentation and instructional methods and an interpersonal one that has to do with the teacher's interpersonal actions that create and maintain a positive classroom atmosphere, the QTI can be said to capture the latter aspect of teacher behaviour. By discerning these two aspects I do not mean to deny, of course, that they are interconnected. Wubbels & Levy (1993b) note in this respect that "[i]f the quality of the classroom environment does not meet certain basic conditions the methodological aspect loses its significance." In fact, concerning the teacher whose lessons I observed during the first year of my research I have made a similar remark (cf section 10.1).

The QTI leads to a characterization of interpersonal teacher behaviour in terms of eight different types of interpersonal behaviour, which can be represented in a two-dimensional plane (cf figure 10.1).
Figure 10.1  The model for interpersonal teacher behaviour. (Figure 2.2 in Wubbels & Levy, 1993a.)

The two dimensions of the plane have been labelled 'proximity' and 'influence.' The 'proximity-dimension' indicates the teacher's degree of cooperation with or closeness to pupils, on a scale between Opposition (O) and Cooperation (C). The 'influence-dimension' indicates the extent to which the teacher directs or controls the interaction with pupils, on a scale between Submission (S) and Dominance (D). In figure 10.1 the eight different types of behaviour are represented by the eight sectors DC, CD, etc, "according to their position in the coordinate system (much like the directions on a compass). For example, the two sectors DC and CD are both characterized by Dominance and Cooperation. In the DC sector, however, the Dominance aspect prevails over the Cooperation aspect" (Wubbels, Créton, Levy & Hooymayers, 1993). In figure 10.1, each of the eight sectors is also characterized in words, both briefly (DC by 'leadership,' CD by 'helping friendly,' etc) and somewhat more elaborately in terms of characteristic teacher behaviour.

The questionnaire itself, the QTI, of which there is a Dutch and an American version, "is divided into eight scales which conform to the eight sectors of the model. In the Dutch
version each sector scale consists of about ten items (seventy-seven in total) which are answered on a five-point Likert scale. The American version has sixty-four items and a similar response scale” (ibid). For a discussion of the reliability and validity of the QTI, I refer to Brekelmans et al (1990).

Figure 10.2 Average teachers’ perceptions of ideal teacher behaviour and average students’ perceptions of best and worst teachers in the United States. (Figure 3.7 in Wubbels & Levy, 1993a.)

"Each completed questionnaire yields a set of eight scale scores which are then combined into a profile ... Scale scores equal the sum of all item scores and are reported in a range between zero and one. A scale score of 'one' indicates that all behaviours in a scale are always (or very much) displayed. A 'zero' is the opposite: the absence of scale behaviours. The profile represents the teacher's communication style as perceived by the teacher or his or her students. It is usually depicted in a graph with scale scores represented by shading in each sector” (Wubbels, Crétou, Levy & Hooymayers, 1993). Figure 10.2 contains three examples of such graphically represented profiles. They derive from three different types of data. "Students in The Netherlands, the United States and Australia were asked to rate their best teachers on the QTI. Also, teachers in the three countries provided self-perceptions about their ideal behaviour. Finally, a smaller group of Dutch students completed the QTI for a teacher they thought of as their worst. Figure [10.2] shows the average scores for these three groups in the United States. The results are similar for the other countries” (Levy et al, 1993). Figure 10.3 may be another profile
of interest. It "shows the average of 463 students' perceptions for a random sample of 118 Dutch teachers." (ibid). So in a sense it represents the communication style of the mean Dutch teacher, as perceived by students.

By using a variety of clustering procedures and similarity measures, Brekelmans (1989) has established a reliable and stable typology of eight types of communication style, such that each profile out of a large number of profiles of Dutch, American and Australian teachers belongs to one of these eight types. By combining QTI data with descriptive data of classroom atmosphere, Brekelmans has also given a description of each of the eight communication styles in terms of teacher/student behaviours and learning environment characteristics. Brekelmans et al (1993) contains, for each of the eight communication styles, both the mean profile corresponding to it and its description in terms of learning environment characteristics.

I hope the above gives sufficient information on the QTI. As I have already noted, the QTI has also been administered to the teacher and to several of his classes that worked with a version of the didactical structure.
Figure 10.4 The teacher's perception of ideal teacher behaviour (a); the teacher's perception of his interpersonal behaviour in one of his classes (b); that class' perception of the teacher's interpersonal behaviour (c).

The profile in figure 10.4a is the result of the teacher's completion of the QTI in terms of his ideal behaviour; figure 10.4b is the resulting profile of the teacher's completion of the QTI for his behaviour in one particular class (in fact, one of the classes in which the first version of the didactical structure was tried); figure 10.4c represents the teacher's communication style as perceived by the pupils in that particular class (it corresponds to the class means of their completion of the QTI). The profiles corresponding to the teacher's perception and the pupils' perception of the teacher's communication style in other classes are similar to figures 10.4b and 10.4c respectively. In fact, in terms of Brekelmans' typology all those profiles are of the type that she has labelled 'Authoritative.' In Brekelmans et al (1993) it is characterized as follows.

The Authoritative atmosphere is well-structured, pleasant and task-oriented. Rules and procedures are clear and students don't need reminders. They are attentive, and generally produce better work than their peers in the Directive [another category in the typology, KK] teacher's classes. The Authoritative teacher is enthusiastic and open to students' needs. He or she takes a personal interest in them, and this comes through in the lessons. While his or her favourite method is the lecture, the Authoritative teacher frequently uses other techniques. The lessons are well planned and logically structured. He or she is considered to be a good teacher by students.

The teacher's ideal communication style (i.e. the one that corresponds to the profile of figure 10.4a) is of the type that Brekelmans has labelled "Tolerant and Authoritative." In Brekelmans et al (1993) it is characterized as follows.

Tolerant/Authoritative teachers maintain a structure which supports student responsibility and freedom. They use a variety of methods, to which students respond well. They frequently organize their lessons around small group work. While the class environment resembles Type 2 [the above 'Authoritative' type, KK], the Tolerant/Authoritative teacher develops closer relationships with students. They enjoy the class and are highly involved in most lessons. Both students and teacher can occasionally be seen laughing, and there is very little need to enforce the rules. The teacher ignores minor disruptions, choosing instead to concentrate on the lesson. Students work to reach their own and the teacher's instructional goals with little or no complaints.

Hereby I hope to have sufficiently characterized the interpersonal aspect of the teacher's classroom behaviour. Let me close this section by noting that the quality of the classroom environment that he manages to create is such that the methodological aspect, on which my research mainly focuses, could indeed be given full consideration. In devising the

3. I want to thank Rob Houwen for the analyses of the QTI data: for producing the profiles like those in figure 10.4, and for determining the type of communication style to which each of them belongs.
didactical structure we have been in the luxurious position that whatever technique or instructional method we proposed (be it group work, class discussion, experimental work, or complex combinations of these), we could always count on the teacher's ability to satisfactorily handle them.

10.3 A preparatory period

Before the teacher and I decided to cooperate on an educational experiment, we had an exploratory talk in which I told something about my ideas concerning the experiment and the teacher about his attitude towards it. I told him that I wanted pupils to meaningfully learn about the topic of radioactivity, that recent research had shown that this aim was very often not reached (not just for the topic of radioactivity, but for almost any topic), and that part of this failure might be due to the fact that most approaches do not start from where pupils are. It almost seems as though for pupils the scientific knowledge they 'learn' is something alien that only has application in the science classroom. I also told him about the cause of our having this exploratory talk: another teacher's decision to quit, and why that other teacher had decided so (cf section 10.1). Of course, I would like to prevent a repetition of that situation. In order to do so I told him I had first of all planned a quite extensive period to carefully prepare a productive working relation. So taking an active part in this preparatory period would be one thing I expected him to do, if he decided to cooperate. Other things would be that he helped in writing new teaching materials (in the first instance in a commenting role), worked with these new materials (while the relevant lessons were being videotaped), etc. What he would get in return were two non-teaching periods and a piece of in-service training that, hopefully, was going to be useful for him.

Of course I also wanted to know how he felt about the aim of my research, however vague it was. In particular I wanted to know, in the context of preventing a repetition of the situation with the previous teacher, whether or not he shared her sceptical attitude. The teacher said to recognize that knowledge does not always function, in the sense that pupils cannot apply it. He told that he thinks that is a problem: it frustrates. So he suspected that he somehow worked on that problem, although it was not a conscious element of his teaching practice. At any rate, from what I had told him he said to have gathered that participating in my research would give him the opportunity to explicitly think and learn about an attempt to tackle that problem, and he certainly did not already beforehand consider such an attempt to be a lost cause. In fact, he said to see no reason why insight would be impossible for middle ability pupils. Finally, the teacher said to hope that by participating in my research he could learn something that might also be of use for other topics than the topic of radioactivity. From this I gathered that at least he had a non-negative attitude towards (the aim of) my research.

On the basis of this exploratory talk the teacher and I decided to cooperate. In this section
I report on the first stage of our cooperation: the preparatory period. In section 10.3.1, I sketch the aims, procedure and outline of this preparatory period; in section 10.3.2, I sketch the way it developed and mention some of its main outcomes.

**10.3.1 Aims, procedure and outline**

The main aim of the preparatory period was to prepare a productive future working relation with respect to writing, trying, etc new teaching materials. In a process in which he came to familiarize himself with (the aim of) my research and I came to familiarize myself with his way of teaching we would have to develop a common way of talking about teaching and learning in general, and about teaching and learning the topic of radioactivity in particular.

The preparatory period took place during the fall of 1989. In that period I visited about one lesson per week, mostly in one of the classes in which later in the school year the first version of the didactical structure was going to be tried. Furthermore, the teacher and I had eleven meetings of about two hours each. The teacher's preparation of a meeting consisted in his doing some homework (of about two hours per meeting). Mostly the homework tasks were given by me, e.g.: study the similarities and dissimilarities between two units on the topic of radioactivity; study some transcripts of interviews with pupils about molecules or radioactivity and relate these to your own teaching about those topics; study some transcripts of fragments of lessons on the atomic model (what are pupils' difficulties and do you recognize these difficulties from your own experience?); study a description of pupils' existing knowledge about radioactivity (along the lines of section 2.5 of this thesis) and comment on it. Occasionally the teacher also set his own homework task, e.g.: carry out a small scale questionnaire study in one class at his school and analyze the results. My preparation usually took me about one working day. It consisted of things like: selecting useful homework tasks for the teacher; anticipating his reactions to it and thinking of ways to build on that in order to clarify some of my ideas about teaching and learning (the topic of radioactivity); studying the conversation we had during a previous meeting (the meetings were recorded on audiotape), and making a reflective report of it in order to identify themes that deserved a further treatment in later meetings; thinking of ways to integrate what I had noticed during visits of lessons in our meetings.

Some of the themes that came up during the meetings were: the aim of the preparatory period and an outline of it; the tendency to base units on the topic of radioactivity on particle models (cf section 3.2); the way such 'models' are often understood by pupils and its consequences for their learning about radioactivity (cf section 3.3); parallels between the teacher's and my learning process during the meetings on the one hand, and pupils' learning on the other; the teacher's role with respect to content: holding back versus steering; the knowledge that seems to be required for an adequate understanding of (the possible dangers of) daily life situations having to do with radioactivity; the usefulness of the meetings.

The teacher's homework for the final meeting of the preparatory period was to write a review of it: on what he had learned from it, on whether through it he felt prepared for a
further cooperation, etc. In the final meeting we discussed his review. The totality of my reflective reports of each meeting can be seen as my review of the preparatory period. Section 10.3.2 is based on it.

10.3.2 Development and outcomes
At the beginning of the preparatory period I had some ideas about themes that I wanted to bring up for discussion (cf the previous section), but I did not really have much ideas about how to structure each of the meetings, about a suitable order in the themes I wanted to bring up for discussion, about useful homework tasks for the teacher, etc. In fact, the latter ideas gradually developed during the meetings and also as a result of my making reflective reports of each of the meetings. Below I sketch and exemplify these developments, the use of my regular visits to lessons given by the teacher, and some of the main things the teacher and I have learned from the meetings.

The structure that the meetings gradually assumed
After a while the structure of the meetings between the teacher and me was based on our awareness that we approached educational matters differently and with different experiences, and took the form of trying to make explicit each other's approach and experiences while discussing concrete material (transcripts of lessons and interviews with pupils, results of questionnaires, textbooks, things that happened in a lesson I visited, etc). Below I exemplify how an analysis of the earlier meetings gave rise to this structure and how this structure was made explicit.

The first meeting was a brief one and concerned the procedural aspects of future meetings (how often, how long, how much preparation, etc). The second meeting was the first one in which we discussed issues. The theme I wanted to bring up then was the obviousness of the tendency to base a unit on the topic of radioactivity on particle models. In order to first of all make clear this tendency, I selected two such units (the unit in the textbook the teacher normally used and the unit *Radiation, you cannot evade it*...), which, although they are quite different with respect to e.g. content presentation, essentially have the same structure. So the homework task I gave to the teacher was to study those two units and capture the main lines of the way each of them is build up. I expected that thus he would also find that the two units are essentially the same and, in particular, both begin with the presentation of a nuclear 'model.' (This would then allow me to ask whether it is obvious to begin in that way.) More or less for the sake of completeness I added to the homework assignment the question what the differences between the units are. It turned out that the teacher had indeed noticed the similarity in structure, which he framed as 'what atoms are; what radiation is; how radiation emerges; what the effects of radiation are;' but that he was most struck by the differences between the two units. He found the unit *Radiation, you cannot evade it*... much more pupil-friendly, especially for middle ability pupils: better geared to them and more surveyable for them. For it consists of relatively short and easily readable pieces of information, each of which is followed by some questions that directly refer to it, it contains regular and short summaries, etc. The other unit, in
contrast, contains many long stretches of text with too high a level of difficulty, which, as was the teacher's experience, a middle ability pupil simply cannot get through.

Our different approach can in this case be characterized as our laying a different emphasis. Although I noticed the difference in content presentation (and had, in fact, selected the two units because of this difference), I emphasized the similarity with respect to structure. And although the teacher noticed this similarity, he emphasized the difference in content presentation. The teacher's emphasis can be said to reflect his practical and pragmatic approach, with an immediate link to his everyday teaching experience. One of the first things he asked me when discussing the two units was: what do you have in mind, something like this unit or something like that one? My own emphasis can be said to reflect my more theoretical approach, which is also related to existing teaching practice but more in the sense of looking at it from some distance and bringing it up for discussion - in this case, the obviousness of the existing tendency to base a unit on the topic of radioactivity on particle models.

What enabled the teacher to also bring in his points was the part of the homework assignment that asked for dissimilarities between the two units. I have already mentioned that at the time I more or less accidentally included that question in the homework assignment, or had at any rate not included it in order to allow the teacher to bring forward his points. If only for the reason that in a period of getting acquainted the teacher should also be given the opportunity to bring forward his own points, for future meetings I very consciously tried to devise such homework tasks, that the teacher, with his more pragmatic approach, and I, with my more theoretical approach, could each bring forward our own points, thus make explicit each other's approach and experiences, and thus also learn from each other. Indeed, it was not just out of politeness that the teacher was given the opportunity to bring forward his own points, and the fact that in the meetings I naturally had to take the initiative did not imply that only the teacher was supposed to learn something. I also learned from the teacher. The teacher's comparison of the two units, for instance, made me realize that in the later writing of new teaching materials I would have to seriously deviate from my normal writing style. Instead I would have to write relatively short and simply constructed sentences that would have to be organized in a whole that is easily surveyable for middle ability pupils. At least in that respect, so I learned from the teacher, I should take the unit *Radiation, you cannot evade it...* as an example.

In later meetings I also tried to make this structure of our meetings explicit: by illustrating it at examples like the one above; by explicitly telling one another what each learned from the other and how that relates to the other's approach; by drawing parallels between our learning from each other and pupils' learning from their teacher (or teacher's learning from his or her pupils). In the fifth meeting, in which among other things we looked back on the previous meetings, the teacher also recognized the structure that the meetings had assumed:

I do also sense it like that. That we are feeling out, catching up from each other. I hear new things, you learn new things. Obviously you take the initiative. Well, that's how I
see it: you are... I'm here for you. I think you have to take the initiative. I think I get all room. If I dwell on something, then there simply is time for that, then we simply keep on talking about that subject. I... up to now... I actually think it's getting easier and easier for me. The first time I thought: Jesus, it looks like an examination or it looks like... I have the feeling that I'm being interrogated about what I do and do not know. And now I don't have that at all. We're simply feeling out: how do we think about some things?

Later on the teacher told me that his initial feeling also derived from his not feeling very safe at the time. He, the dumb teacher, had to go to a place where he did not really belong: The University.

Of course the teacher and I gradually grew closer to each other. When in later meetings we e.g. discussed some transcripts of lessons, the teacher would bring forward points that I also found relevant, and for very much the same reasons. The main difference between us then was that I usually brought forward more similar such points, which the teacher, after I brought them forward, mostly also recognized as similar. At first this difference in quantity gave the teacher the impression that he had not done his homework well enough and, in fact, made him feel sort of guilty. Of course, I then told him that there was no need for such impressions and feelings. On the contrary, the fact that he focused on very much the same points as I did was evidence for the fact that our approaches converged with respect to some themes. The difference between us then no longer was a matter of different approaches, but rather of different amounts of time spent on homework assignments.

**Shifts in theme: from content to didactics**

There usually also was a shift in theme in each meeting, which at first again occurred rather accidentally but, after I had noticed it in earlier meetings, was planned more consciously in later meetings. I would characterize the shift as one from content to didactics. Let me again try to illustrate this at the meeting in which the two units were compared. The question concerning the similarity between the two units can be said to deal with content, in the sense that its answer is that with respect to content the two units are essentially the same. On the basis of that answer, which as already noted the teacher had also given, our discussion gradually developed in a didactical direction in the sense that the structure of the content presentation was related to teaching and learning. To my question why the units begin with atomic models, the teacher's initial response was as follows.

This book simply assumes that... I later have to tell about those isotopes with which something special is up, so I first have to tell what isotopes are. [...] In order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you can't explain it. But you think it can be done differently?

The teacher's argument is of course valid within the existing structure of the units. But it was this structure that I wanted to bring up for discussion. I tried to do so by noting that beginning with atomic models is like beginning on the most advanced level. Is it not possible to already say something about radioactive phenomena without using particles, without immediately going deeply into the theory behind them? This at least made the
teacher understand that I wanted something that differed from the existing structure.

You don't want to begin with... straight to the smallest particle and everything is connected to those smallest particles. You want to begin with... what does happen, how could that be, search... arouse interest... and first spend some time on that before we go more deeply into it, right?

I then tried to link up with his 'to arouse interest' in the sense of 'to induce a need for a deeper explanation,' an explanation at any rate of something they already know at a phenomenological level. The teacher put this in his own words as follows:

Would they be more inquisitive, that really is... more eager to learn about the particle model if they are going to hear about it later? First, what is it and what do we notice of it and effects, slowly settling in, and only then the explanations.

This 'to make pupils eager to learn about something,' which fitted into my developing ideas about a problem-posing approach, is a didactical theme that often recurred in our subsequent meetings.

Another more didactical theme that the teacher had picked up from this meeting is the following: is one thing really needed as a preparation for something else? This turned out when several meetings later he came back on his earlier statement that "in order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you cannot explain it," and concluded that it is possible to talk about isotopes without first having to talk about atomic models, which was in fact his first step in loosening himself from the existing structure. His reasoning was that all that is really needed to understand the concept of isotopes is the idea of slightly different things. He used the example of a bag of a hundred white marbles, of which on closer observation it turns out that one has a little crack and one a little black spot. By calling the three possibilities (perfect white marble, marble with little crack, marble with little black spot) three isotopes of white marbles, pupils could thus get the idea of what an isotope is without having to know anything about atomic models. He went on by noting that also in a subsequent treatment of atomic isotopes, there really would be no need to talk about protons, electrons or differing numbers of neutrons. All that needs to be said is that some atomic isotopes are different in the sense that something special can happen to them. I then elaborated on the theme the teacher brought forward, for I believed that he was very close to noticing that it is possible to talk about 'the something special that can happen to them' in other terms than changes in microscopic structure. I tried to do so by admitting his conclusion that it is possible to talk about isotopes without having to talk about atomic models, and by going one step further: is it also possible to talk about radioactivity without having to talk about isotopes? The teacher thus came to the insight that it is possible by simply calling something radioactive if a Geiger counter starts ticking in its vicinity. I could then also inform the teacher that I had this possibility in mind as a means to start up the series of lessons we were going to devise.

The didactical theme brought up here by the teacher also came back in later meetings. When later on we e.g. discussed the general constraints on the series of lessons we were going to devise, it returned in the following form: an activity should be meaningfully prepared by preceding ones and meaningfully prepare following ones.
When thinking about a suitable order in the themes I wanted to bring up for discussion, I also tried to make use of the idea 'making someone eager to learn about something.' That is, I tried to arouse the teacher's interest in a new theme on the basis of previous themes. In some cases I succeeded in this. The teacher for example understood why on the basis of the meeting in which the two units were discussed, I gave him the homework assignment to study some interviews in which pupils were prompted to give particle explanations.

You want to get rid of that particle model in your new planning. [...] We teach them that all right, those particles and how all of that... but can they themselves handle that too? For, of course, if you find out, they cannot handle that at all and haven't formed any idea at all of... then you will be on strong ground in saying we have to try it in a different way.

When shifting to a didactical theme I often used such concrete examples from our own meetings as a means to bring it up for discussion. If possible I would, for the same purpose, also use concrete examples from the lessons I visited.

Apart from shifts from content to didactics within one meeting, in retrospect I notice a similar shift in the course of the meetings as well. In later meetings we more often and more directly discussed didactical themes, e.g.: pupils enter the classroom as empty vessels versus pupils have a background and this background influences their participation; explaining versus challenging pupils to find things out by themselves (as a form of making them eager to learn about something); asking pupils questions versus making pupils ask questions (as a form of making them eager to learn about something).

In discussing such themes, the teacher was of course especially interested in the consequences for his own role in the classroom. In fact, our discussion about his role was one an ongoing one. It continued during the following construction, try-out, reconstruction, etc of the didactical structure (cf section 10.4). In the preparatory period we often talked about the teacher's role in relation to yet another didactical theme: holding back versus steering. We tried to sort of take stock of the various ways in which these terms might be given content, if possible by using concrete examples. Steering or helping pupils, for instance, need not only consist in explaining. Pupils might e.g. also be helped in their learning process by making them arrive at some problem that they themselves come to see as worthwhile to work on. 'Holding back,' on the other hand, is not meant as 'withdrawing' or 'laisser faire.' It might e.g. be given content in the form of 'getting into the skin of the pupils' and 'trying to learn along with the pupils.' Since the preparatory period was also meant as a preparation for the coming construction of a series of lessons, in the later meetings we more and more began to talk about that as well (as part of our shift towards more didactical themes). In that context it was concluded that a substantial steering role should also emanate from the design of the series of lessons. In the construction of the series of lessons, we would have to think out such tasks and such an order in tasks that we have al reason to expect that by working on them pupils are steered in the direction of some goal (e.g.: their recognition of some problem). 'Holding back' might in that context be given content as sort of opposite to 'seeking confirmation of our expectations' or 'pursuing our goals at all cost.' Whereas the latter two attitudes do not prepare the ground for a meaningful evaluation, holding back in the sense of trying to
learn along with the pupils may bring to the fore both the need for adjustments concerning (the order in) tasks, expectations and/or goals, and suggestions for plausible such adjustments (cf section 7.4.3).

Use of visits to lessons

One aim of the preparatory period was to familiarize myself with the teacher's classroom behaviour, i.e., in the terminology of section 10.2, both with his methodological and his interpersonal teaching style. In this respect my regular visits to his lessons were of course useful. They were also of use for our meetings, however, as I now try to illustrate. Let me first of all repeat that in our meetings we mainly focused on the methodological aspect. The interpersonal aspect of classroom behaviour, and in particular the teacher's interpersonal teaching style hardly came up in our talks. In the first place I did (and do) not feel competent to discuss the latter aspect. Secondly, it seemed to me that in his case there was hardly any reason to discuss it (cf section 10.2). So concerning this aspect I limited myself to occasional remarks how well I thought he managed to create and maintain a pleasant and productive working atmosphere.

Especially during our first meetings, I tried to bring forward some features of his methodological teaching style that I had picked up from visiting his lessons. He e.g. hardly ever gave a direct answer to pupils' questions, but instead tried to challenge them to themselves find the answer, if necessary by giving some casual clues: 'I don't know, but might it be that...' He would then some time later come back to see how they were doing and, if necessary, help them yet another bit further. Out of examples such as these, and the teacher's comments on them, eventually grew didactical themes such as: explaining versus challenging pupils to find things out by themselves; asking pupils questions versus making pupils ask questions; holding back versus steering.

In the above I have already repeatedly mentioned this aspect of the use of my visits of lessons, i.e., to have available concrete examples that both of us witnessed. Those examples could then e.g. be used to make explicit each other's approach, to start a discussion about further or similar experiences, to bring up or illustrate other didactical themes, etc.

Another aspect of the use of my visits of lessons derives from the different approaches of the teacher and me. One of my aims of our discussion of some interviews in which it was tried to make pupils give particle explanations, for instance, was to explore why pupils failed to do so, and this aim reflects my more theoretical emphasis. The teacher's more practical and pragmatic approach, with an immediate link to his everyday teaching practice, is e.g. reflected by the fact that following our discussion he wanted to find out about his pupils' ability to give particle explanations. Moreover, and in this sense my visits, and particularly the ones at the beginning of the preparatory period, provided a stimulus for him to try things out in my presence, so that we could later talk about it. Later on, however, he no longer needed my actual presence in order to try things out. It was then rather his own enthusiasm that made him do it. Of course, he would then still report about his experiences in a subsequent meeting.
Some learning outcomes

In his review of the meetings, the teacher indicated what he had learned from them:

Well, one of the things that have most struck me is that much more than before I wonder whether my way of teaching, treating the subject matter, observing and evaluating pupils... is done in the right way. Less than before I rely the old routine in which, as I have come to realize, I was somewhat getting stuck. So you could now describe it as greasing the whole thing in order to counter the getting stuck.

Also during the meetings themselves he had already made similar remarks, e.g.:

...you are confronted with what you are really doing the whole day, and self-evidently so.

So you see, not just here I am wondering... but also during my lessons I am... it already is on my mind. Well, why am I doing this? I do not wonder whether I am doing it right, really, but could I do it differently, does it make sense that I tell it to them, what do they really pick up from it, what will they do with it?

So the teacher has experienced the meetings as useful, as refreshers of his teaching practice in general. This may also be illustrated by the enthusiasm with which he tried things out that were discussed in meetings.

More in particular, the teacher has also experienced the meetings as useful. Concerning the themes relating to content, for instance, he indicated to have become sensitive to the problems that pupils have with particles and to the question whether a treatment of the topic of radioactivity should be based on particle models. He in fact admitted to have been shocked by the poor understanding that pupils have of particle models. And his pupils too, as he found out when in one of his classes he challenged the pupils to explain why a roadway expands on a hot day and they came up with answers such as: the molecules expand, the air between the molecules expands, or the intermolecular spaces between the molecules expand. Here is one more example of the influence that in this respect the meetings have had on his teaching practice:

Today, for instance. [...] Someone drops the word 'molecule.' Another one immediately says: the smallest particle of a substance with all its properties. Never ever would I have reacted to that. That is correct. Today we have talked about it for a quarter of an hour. Have talked about it for a quarter of an hour! Would it really be like that? [...] I don't know whether those pupils have gained anything from it. But at any rate it is the result of these meetings.

Concerning the didactical themes, the teacher wrote in his review that especially our recurring discussions about 'holding back and steering' had been very instructive. He also indicated to have gathered from the totality of our meetings that I am a proponent of "letting pupils themselves experience, describe and tentatively process, instead of the traditional model of learning, digesting and testing." In this respect too the teacher noted that the meetings have had their influence on his teaching practice, e.g.:

...I more often try to get into the skin of the pupils...

It has already yielded fruit (still to be seen whether it is ripe) in my daily teaching practice. Holding back, listening to pupils, adjusting a little later. A changed attitude with regards to pupils' making notes of observations. Less direct 'explaining.'
The main thing I learned from the meetings was to further specify and illustrate what the consequences for the teacher's role are of my ideas about how pupils could meaningfully learn about the topic of radioactivity. For up to then those ideas mainly concerned pupils' learning process, e.g.: whether for pupils one thing (e.g. particle models) really is a meaningful preparation for another thing (radioactive phenomena). Of course I had some ideas about the teacher's role in pupils' learning process, but it was the teacher, with his pragmatic demand for immediate applicability to his practice, who continuously challenged me to do further develop those ideas and also contributed to that further development. For me too, our discussions about 'holding back and steering,' and particularly about how the notions 'holding back' and 'steering' could be given further content in relation to my developing ideas about a problem-posing approach, were most instructive.

Another thing I learned from the way the meetings themselves proceeded, was how useful it is to regularly and explicitly build in reflective activities. For it had been beneficial for our meetings that each of us regularly thought about, and that we then explicitly talked about, questions such as: what have we done, what have we achieved and where does that leave us? So it would also be useful, and moreover in line with a problem-posing approach, to build in such activities in the series of lessons we were going to devise.

Some of the minor, but still important, things I learned also relates to the construction of the series of lessons. The textbook that pupils are to work with should be carefully edited, and easily surveyable and readable. It should be clear to them that quite some time and effort has been put in it, in order to increase their willingness to seriously work with it. The latter point may be compared to a remark that the teacher made in his review, namely that it was also due to my careful preparation of the meetings that he was challenged to invest quite some time in the homework assignments.

I conclude that our preparatory period had met most of its aims. I had come to familiarize myself with his way of teaching. He had become sensitive to the problems with the existing structure to treat the topic of radioactivity, and had gathered some ideas about an alternative structure. We had developed a common way of talking about teaching and learning that promised to be useful for a productive future working relation with respect to writing, trying, etc new teaching materials. Particularly the theme 'holding back versus steering' seemed to be useful for both of us. For the teacher because it directly concerned his role; for me to further think through what, in terms of holding back and steering, the consequences for this role are in a problem-posing approach. I felt prepared for our future cooperation, and so did the teacher: "I'm one hundred per cent behind the experiment. I have confidence in it."

What had not become clear, as the teacher remarked in his review, is "what precisely the lines are along which and why your research takes place." I guess I myself also did not know that at the time.

10.4 Cooperation during the (re)construction and try-out of the
didactical structure

Following the preparatory period, the teacher participated in my research for a period of two and a half years. In this period he worked with both versions of the didactical structure and was also involved in the construction and evaluation of them. In this section I describe some aspects of our cooperation in this period, and in particular how in this period our discussion about his own role in the classroom continued, with the eventual aim that he made himself so familiar with the essence of (especially the second version of) the didactical structure and his role in it that he would not deviate essentially from it.

10.4.1 Construction and try-out of the first version

For the construction of the first version of the didactical structure there was about three months available. In these three months I had to put flesh to my still vague ideas about another way to structure the treatment of the topic of radioactivity (e.g.: not begin with particles but rather end with them), by thinking of suitable tasks and a suitable order in the tasks. Choices had to be made (sometimes rather ad hoc) in order to meet some constraints: the total series should take about 10 lessons (of 50 minutes), applications of radioactivity should be treated, the examination syllabus had to be covered, etc. Furthermore, a textbook for pupils had to be written, edited and laid out in such a way that for them it would be challenging to work with, and easily readable and surveyable.

At the end of the three months there was indeed a pupils' textbook but, as it had been produced under heavy time-pressure, I was not quite satisfied about it. I did have the feeling, however, that it was worth being tried in the sense that from the try-out we could learn a lot about possible improvements.

In those three months the teacher was one of the people who commented on my intermediate products, and what occupied him most was to see how the vague ideas about an alternative structure that we had talked about during the preparatory period gradually assumed a more definite and concrete form. There simply was no time left to discuss his role in relation to the material that was being written any further than whether he thought it feasible to do the activities in the time that was planned for them. Moreover, the teacher guide that was also being written, was more a justification of the new structure of the treatment of the topic of radioactivity than a practical guide. So also concerning the teacher's role I had the idea that a lot could be learned from the try-out. It was in the evaluation of the first version of the didactical structure that the main work had to be done, with respect to both the structure itself and the teacher's role in it.

The first version of the didactical structure was tried in two classes. The procedure of the class observations had been much the same as later in the try-out of the second version (cf. section 9.2.1). In one of the classes the lessons were recorded on audiotape, in the other on videotape; on the basis of the experiences in the class in which a particular lesson was given first, some changes were sometimes made concerning the matching lesson in the other class, etc. But whereas the procedure of the observations was similar, the first impressions from the observations differed markedly. For, in line with the above mentioned expectations, the first impressions I gathered during the try-out of the first
version the didactical structure were that it certainly was not yet 'good enough.' That is, too often the things the pupils did and said were too far out of line with what they were expected to say and do. Moreover, whereas in some cases rather cosmetic changes might suffice to improve matters (e.g. by avoiding unspecific terms in the formulations of the tasks, cf section 7.4.1), in others more structural improvements seemed necessary. In order that pupils perceive the coherence in successive tasks (cf section 7.4.2) or come to appreciate some problem in the right way (cf section 7.4.3), for instance, it seemed necessary to not just superficially change some tasks but also to change their function and aim, and the way in which they are to be put in a coherent structure.

After the try-out of the first version the teacher was asked to write down his first impressions. The following may give an idea of what they were.

The last weeks before the start of the series of lessons were marked by a lot of pressure, concerning the normal work at school as well as the preparation of the start. [...] In addition to this the material still had not got its definite form and a remark of [one of the other people who commented on the material] about the amount of subject matter and the in his opinion too optimistic planning had made me doubt about the possibilities of the material. After in the end the material had got its definite and carefully edited form my concerns were somewhat taken away again.

Once the lessons had begun I was glad to have the opportunity to always teach the lesson once again in the other class in order to then deal with problems that had been found in the first lesson. Because of that it turned out that after four lessons I myself got the feeling that the planning was feasible and my decreasing tension for the lessons of course made that the further lessons proceeded less tensely.

10.4.2 Evaluation of the first version and construction of the second version

The above may already indicate that at the beginning of the evaluation the teacher and I had a different attitude, which may again be characterized as the difference between a theoretical and a pragmatic attitude. For me the real work still had to begin, and I was sure that the evaluation would lead to suggestions for structural changes, for substantial changes in the didactical structure itself. For the teacher, however, things had worked out well, and by this he meant things like: we made it in time, the pupils learned something and they were involved.

In the first stages of the evaluation this difference was not properly taken into account, however. We had weekly sessions, for which we prepared by studying one lesson. The teacher studied the videotape of that lesson, i.e., the lesson in one of the classes. I studied the videotape too (together with Hans Créton and Wout Moerman), and also the audiotape of that lesson (i.e., the lesson in the other class) and pupils' notes. During the session we then exchanged our findings. At least, that was the plan. It turned out, however, that there was hardly any exchange, but rather a one-way transmission from me to the teacher, in which I pointed at numerous cases in which what the pupils did and said was (far) out of line with what we had expected, at cases in which the teacher's role could have been better, at possible suggestions for improvements in the didactical structure itself and the teacher's role in it. I was far from content about this one-way traffic. The teacher, on the other hand, felt sort of guilty for not having enough critical remarks. So
the sessions were increasingly dissatisfying for both of us.

In order to escape this situation, we spend a session on the sessions themselves. Below are some fragments of what the teacher then brought forward, which also illustrate our different attitudes.

I've looked quite differently at [the lessons]. I think: I have my material, I give my lessons, well, I think that my pupils have learned something of it, right. You've looked quite differently at it, because your starting point was: well, we'll see whether the pupils have learned something of it. Well, I don't look that way at lessons, I don't look months back. I think: well, the lessons are over, we have made it in time, so I was satisfied, right. So I thought that the lessons went well. If you're looking at it through such a magnifying-glass, well, then indeed you're going to say, and I really do admit that now too: what we had expected did not quite come out and it might have been done differently.

[During the try-out] I myself didn't have the idea that we were going to discuss it that well, that accurate, that we'd go that deeply into it.

So I really am content about the sessions, about the way we're working on it, but it is different from what I had imagined. Much more about small things, of which you say: here, see that, now? [...] I found it for instance nice... a nice example, that that second lesson I had watched, that I had hardly made any notes really and that I tell you those and that you then come with [...] no less than thirty remarks, well, five pages full. And if I read them over, then I think: and it is like that too. Well, and that you pull them out much more easily than I do. I obviously take notice of quite different things: whether the children are participating, or that they... I don't take notice of whether they... And I do think along with you whether it can be done differently, but I do not pick it out myself.

We concluded that it had been a kind of strange experience for the teacher to look through a magnifying-glass at the small things of something that was well over and that on the whole he was quite satisfied about. On the other hand, now that he got used to the idea he also appreciated that by looking this way it became clear that what we had expected did not always come out and that things might have been done differently. In fact, the teacher also indicated that through the evaluations he had become aware that during the try-out he had not grasped the point of some activities, which accordingly he had not carried out very well, and had also become aware of other cases in which his role had not been adequate. Furthermore, the teacher indicated that the many small things added up to suggestions for quite structural changes, which he appreciated as improvements: "It is a whole different approach, it is quite a different approach. I do think so. The new design appeals to me."

So the main source of the problem seemed to us that, although he did think along with me and appreciated the points I brought forward, the teacher himself did not pick out the things that I did and did not himself come up with suggestions for structural changes. It was not so much problematic that I picked out more things and that I came up with the suggestions for improvements. After all, I had given the didactical structure a lot more thought than the teacher had. Moreover, it was precisely in this period that things began to fall in place for me, that I began to arrive at the global outline for a didactical structure
as outlined in chapter 6. So it was quite naturally that I took the lead concerning the structural aspects. What was problematic, however, was that in the sessions up to then this inequality had not been properly taken into account. For the teacher had the same general assignment that I had: study a lesson and comment on it.

As a solution to the problem we suggested that each of us would study the lessons with a special assignment. I would especially focus on the structural aspects, e.g.: whether the things pupils do and say is in line with what they were expected to say and do; whether by changes in formulation, aim, function, order, etc pupils might come to perceive the coherence in successive tasks or come to appreciate some problem in the right way, etc. The teacher, on the other hand, would especially focus on, what we called, the procedural aspects, e.g.: whether the way in which an activity was carried out has contributed to reaching the aim of the activity; whether by changes in instructional technique or teacher participation (more) pupils might come to (better) appreciate some problem in the right way, etc. Of course the structural and procedural aspects hang closely together. So the teacher had to keep on thinking along with me with respect to the structural aspects, though he was no longer expected to make substantial contributions concerning them. And of course I had to discuss the procedural aspects with him, and in particular their relation to the structural aspects.

It turned out that by the above division of tasks the problem was indeed solved. Firstly, it made more clear that both concerning the structural and the procedural aspects the series of lessons needed to be considerably improved, and also which were the structural and which the procedural improvements. Secondly, the teacher's new task was directly related to what most concerned him: his own role, and he was willing, and able, to work on his new task. Thirdly, the new task was a good preparation for his task during the writing stage of the second version of the didactical structure, namely to write his own guide. His new task, finally, enabled us to continue our discussion about his own role in the classroom, which in the preparatory period we had already begun, and this time more concretely in close relation to the didactical structure.

So the teacher began to study the tapes again, this time especially focusing on the procedural aspects. In the terms of our theme 'holding back versus steering,' he noticed that there were many cases in which his participation had been far too steering. There were cases in which he virtually took over an experiment that pupils were performing, put words in their mouths, heard and saw much more in what pupils said and did than what they actually intended to say and do (cf section 7.4.3), was too focused on pulling out the desired answer (as in: "I've already heard the right answer"), he tended to address himself to especially the 'better' pupils, etc.

Obviously we did not discuss such cases in a blame-context, but acknowledged that a lot of them derived from the fact that the whole thing had been new and stressing for the teacher. He had been nervous, especially during the first lessons (cf his review of the try-out). He had felt the responsibility to make it happen as expected, and therefore was very much focused on the desired answers, apt to hear and see more than there was to see and hear, etc. He also had his initial doubts about the possibilities of the material, whether the
The teacher's role

pupils are indeed able to find things out for themselves or in the time planned for it, and therefore he had sometimes tried to speed things up by putting the words in pupils' mouths, taking over experiments, addressing himself especially to the better pupils, etc. Furthermore, sometimes our expectations had simply been too high, so that on the spot the teacher had to deal with unexpected situations. I also think that keeping a tight control with respect to content was an ingredient of his way of keeping order.

In our discussions I rather tried to make the teacher take two steps. First, to gain confidence both in the material and in the pupils. That is, the tasks, certainly when the suggestions for structural improvements are taken into account, are such that the pupils are indeed able to take control over their progress with respect to content, that also without a tight control of him in that respect they are willing and able to themselves think of experiments, carry those out, draw conclusions, formulate questions, etc. So with respect to content the steering part of the process should be initiated by the material and further driven by the pupils as they work with the material. The second step relates to the procedural aspects: to find ways to so guide the process that, on the one hand, all pupils are involved, make contributions, listen to each other, etc while, on the other, the process still proceeds orderly and structured.

In the first step we discussed cases in which, as the teacher himself had already noticed, his participation had been far too steering, and compared those to cases in which he had appropriately held back. Sometimes it was even possible to make this comparison with respect to the way that one particular activity was carried out in the two classes. This was the case, for instance, concerning the task whether or not the cleaners of an X-ray department need lead aprons. In the one class pupils were divided over the matter. The teacher subsequently gave both sides the opportunity to convince each other, an activity that he ingeniously managed by imposing the rules that the two sides have to take turns in bringing forward a point, that someone who wants to bring forward a point for his or her side has to stand up and that only someone who is standing up is allowed to speak, and that pupils are allowed to switch sides each time one side has made a point. Since neither of the sides turned out to be able to make a convincing case, the pupils were then asked to think of an experiment that could be done with the material present in the classroom and that might decide the issue. The pupils proposed to put the X-ray machine on for a while and then measure whether its walls had become radioactive. The final conclusion, on which everybody agreed, was that lead aprons are not necessary. In the other class, however, things went rather differently. There all of the pupils initially agreed that lead aprons are needed. This unexpected result (he had expected that, as in the other class, the pupils would be divided over the matter) so unnerved the teacher, that he completely took over from then. He forgot to let the pupils think of an experiment that would prove them right. Instead he called a pupil forward, told him to put the X-ray machine on for a while, to then measure the walls with a Geiger counter, and concluded that lead aprons are not necessary. This conclusion lead to quite some protests from the pupils, probably because they did not have the faintest idea why the experiment had been carried out. They

4. In the second version of the didactical structure this task returned (cf section 8.4.2), but, due to some structural changes, at a different place.
certainly had not decided for themselves that it is an experiment by means of which it can be decided whether or not lead aprons are needed. Consequently, the experiment played no role in their further reasoning. What had become clear to the pupils, however, is that the teacher had launched an offensive at their communally held opinion that lead aprons are not needed, and they began to passionately defend that opinion, e.g.: dust particles or the air in the X-ray department have been irradiated and therefore are radioactive. The experiment also played no role in the teacher's further reasoning. Instead he tried to explain why e.g. dust particles cannot have become radioactive, pretty soon got stuck in the explanation when he noticed that in it he would have to use the not yet settled concepts of irradiation and contamination, and ultimately saw no other possibility than to force the matter: as you will learn in the next chapter, irradiated dust particles are not radioactive. At that stage it had of course become clear to the pupils that the teacher very much wanted them to say that lead aprons are not necessary. So in the end they decided to meet the teacher, at least part of the way: okay, the cleaners do not need lead aprons, but they do need something else. So here we had a case where the teacher's very steering role had rather been detrimental to pupils' learning process. If the teacher had given the pupils the opportunity to themselves steer their learning process (by letting them, as the pupils in the other class, think of an appropriate experiment), then they would have been confronted with experimental facts that, for good reasons, they themselves had brought forward. The further discussion could then have been based on facts (on what is seen and heard) instead of vague speculations and not yet justified conclusions, and would then not have proceeded in an undesirable attack-and-defence context.

In the second step, the teacher thought of ways to so structure the classroom process that as much pupils as possible are given ample chance to take control over their progress with respect to content: in which cases group work is most appropriate and how it could best be organized; in which cases a class discussion is most appropriate and how it could best be initiated, guided, rounded off, etc. It was of course clear to the teacher that giving the pupils control over their learning process does not imply his withdrawal, especially not if the process is still to proceed orderly and structured. On the contrary, it requires him to draw on a whole repertory of management techniques. So the teacher studied which such techniques he had already spontaneously used (in the above I have given an example), how they had worked out, where else they could be applied, and he explicitly thought of other techniques. As it was part of his way of keeping order, for instance, to be very much present and in particular to be speaking quite a lot, we thought of a way to combine this with not taking over with respect to content, e.g.: when pupils were carrying out an experiment he could physically withdraw, but verbally be very present as a kind of commentator.

As my evaluation of the first version, via ever more concrete suggestions for structural improvements, gradually transformed into the construction of the second version, so the teacher's second step gradually transformed into writing his own guide for the second version, i.e., into a detailed specification of the instructional techniques and his role in the activities that were planned in the second version. This guide was indeed very much geared to the teacher himself, and contained all sorts of reminders that especially
concerned him, e.g.: do not yet go into it; aim at mutual agreement; do not take over!; try to involve especially the 'lesser' pupils in the discussion; do not run ahead of things; take stock of all suggestions and solutions. Writing his guide was at the same time the teacher's preparation for the try-out of the second version.

**10.4.3 Try-out and evaluation of the second version**

At the start of the try-out of the second version of the didactical structure, both the teacher and I had quite some confidence in it, i.e., we both expected that it would come out as 'good enough.' Both of us also expected that the teacher had made himself so familiar with the essence and details of it and had so well prepared his role in it, that he could carry it out as intended. In chapter 9 I have already tried to show that both expectations came true, although some structural as well as procedural modifications were still necessary (see e.g. section 9.4.1). I also refer to chapter 9 for a description of the cooperation between the teacher and me during the try-out and evaluation of the second version.

After the evaluation, the teacher has written a draft teacher guide that is no longer meant to be especially geared to him. It can be characterized as a shortened and more easily readable merger of (parts of) chapters 8 and 9 of this thesis, i.e., a justification of the main tasks, augmented by pupils' reactions to them and some practical clues for teachers. Out of this draft teacher guide I now quote some fragments of the closing section in which the teacher himself gives a general evaluation of the material.

Once I described the material as 'the engine,' the 'fuel' for which is represented by pupils' contributions. Now that I've worked for several years with this material, I've discovered that this metaphor is not that badly chosen at all. The pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions. And even to the extent that the engine always got that well run in that almost as a matter of course it made its way through the topic of radioactivity. [...] Apart from that all, I in fairness have to tell that teaching in this way, with 'holding back' and 'listening,' does require quite an effort. After these lessons I generally was more tired than after lessons taught in my old way. The question then presents itself whether that additional effort balances the achieved result. I do give this question a cautious 'yes,' though. The design of the material (its structure, emphases and basic assumptions) has more appeal to me than the traditional treatment of the topic of radioactivity. Furthermore it is my experience that practically throughout the series of lessons the pupils enthusiastically continue to take part. In evaluations of the unit the pupils themselves too indicate that they have experienced 'learning from each other' and 'having come to solutions oneself' as positive [cf section 9.6, KK]. [...] I have confidence in the strategy described in this guide. You too will have to get confidence in it. All I can say is that in my series of lessons on the basis of this material [...], the necessary fuel for the engine has always been sufficiently supplied by the pupils. To put it differently: I've never been afraid that we would come to run dry; we've never even driven on the reserve tank.

**10.5 Some general remarks on the role of a teacher**
In this section I try to go beyond the educational experiment that this thesis reports on, i.e., beyond this particular teacher that has worked with this particular material in this particular research. In doing so I also go beyond a firm ground of experiences to base my opinions on and, to some extent, beyond my competence. So this section is of a speculative nature and should accordingly be read as a representation of some of my personal ideas. Let me begin with going beyond this particular topic. This is what the teacher has to say about it (in his draft teacher guide).

My most important finding, though, is that you will not be able to work with this material if you haven’t at least come to believe in its basic assumptions, e.g., confidence in the importance of ‘postponing questions’ and ‘holding back’ of you as teacher. Are these basic assumptions and strategy also applicable to other topics from the physics curriculum? I do think so: postponing questions will be going to function as something normal for the pupils. Especially if more often they notice that the answers are found (and often by themselves) as a matter of course. [...] Thinking of experiments oneself and drawing conclusions from those is, according to me, also of use for more topics. Does all this mean that in your physics classes you will tomorrow be able to begin with ‘holding back,’ postponing questions, letting pupils themselves think of experiments, carry those out and note down conclusions? The answer to this question is a very distinct: no! Material that makes possible such an approach for other topics simply isn’t available. But if such material is to come, and it isn’t up to me to take care of that, I will surely use it.

Like the teacher, I believe that the basic assumptions and strategy are applicable to other topics as well. In fact, in chapter 6 I have already quite generally presented a global outline of a didactical structure. I also think that the teacher will be able to work with material that, for some other topic, makes possible a similar approach, i.e., with a ‘good enough’ didactical structure of some other topic. I also think that it would not take him that much preparation time as his learning to work with the didactical structure of the topic of radioactivity has taken him. After all, he does already believe in the basic assumptions and strategy, so his preparation would simply be a matter of finding out how the basic assumptions have been detailed and how the strategy could be detailed for the case at hand. In all this, he would of course draw on his experience with (working with) the didactical structure of the topic of radioactivity. I also think that the teacher himself would not be able to construct, for some other topic, material that makes a similar approach possible. This, of course, is no disgrace. I myself, for instance, think that I am able to construct didactical structures for other topics, and that those (re)constructions will much quicker converge to ‘good enough’ didactical structures than has been the case for the topic of radioactivity, but I do not think of myself as good enough a teacher to be able to work with such didactical structures without any further training. But, as I have already noted, all this is speculation.

Let me speculate a bit further and ask whether other teachers than the one who participated in my research are able to work with the ‘good enough’ didactical structure of the topic of radioactivity (or some other ‘good enough’ didactical structure), and what it takes to make them able to do so. One thing that it takes, as the teacher who participated has repeatedly emphasized, is confidence in its basic assumptions and strategy on the one hand, and in the pupils on the other. In order that other teachers gain such confidence, I
do not think it is necessary that they go through the whole process that the teacher who participated has gone through (and that has been the main topic of this chapter). Neither do I think that it will be necessary that they study the theoretical background, i.e., something like chapter 4 of this thesis. What I think might be useful is that they actually have lessons that are based on the 'good enough' didactical structure at hand and that they watch videos of (fragments of) lessons in an actual classroom. As a pupil and an observer they will thus, as it were in play, get acquainted with why and how the didactical structure is as it is. What they will have to gain confidence from, I guess, is that they see it working, that they also are impressed by the fact that "[t]he pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions." I do not know whether this kind of in-service training will work. We have not (yet) got any experience with it. The teacher and I have run a couple of workshops at a teacher conference, however, in which we, be it in a time span of just one and a half hours, tried to do the sort of things just mentioned. And the fact that most teachers present at our workshops were quite enthusiastic about it, is an argument in favour of attempting an in-service training along the sketched lines.

However, having gained confidence in its basic assumptions and strategy is one thing, being able to work with a 'good enough' didactical structure quite another. It requires, for instance, that one can rather flexibly draw on a quite extensive repertory of management techniques. In the terms of Brekelmans (cf section 10.2), I would without any reservations advise only teachers with an 'authoritative' or 'tolerant and authoritative' communication style to work with a 'good enough' didactical structure. They seem to be the best teachers anyhow, no matter what instructional methods they use. Whether, and how, someone (e.g. a student teacher) can acquire the sort of desired management techniques or communication style is beyond my competence. I do think, however, that such an acquisition will involve the abandonment of some of the common ways in which (student) teachers (learn to) structure lessons, often as a means to keep order. This was once more brought to my attention by Marjolein Vollebregt, a PhD-student who, concerning her first attempts to write a didactical structure (for the introduction of particles, see e.g. 1994), had written in the diary she keeps: "I still don't succeed in writing a scenario that starts from the pupils. Too strongly I hold on to the activities and aims with respect to content in order to maintain with those the common control of the teacher."\(^5\) In a verbal explanation she said that as a student teacher she had learned to structure her lessons as follows: set your goals, i.e., what pupils should be able to do at the end of the lesson; think of activities that are needed to achieve that; think of ways to control that the activities are indeed carried out as desired. So she had learned to think about the appropriateness of activities from the point of view of the teacher's aims and not from the point of view of pupils' motives. And she had learned to keep a tight control with respect to content, especially as a means to keep order, i.e., as a means to survive in the classroom. Now, of course, I also want student teachers to survive, but I wonder whether for that purpose it is necessary that they learn to structure their lessons and to

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5. Quoted with approval.
keep order as indicated above. Are there no other ways that are still within the reach of student teachers? It seems to me that such questions concerning the interconnection between the methodological and the interpersonal aspects of teacher behaviour deserve a thorough investigation.