Getting sensitive to the ways of reasoning of pupils as well as of student teachers

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In learning physics, the development of concepts and ways of reasoning is central. A moderate constructivist point of view says that knowledge cannot be transferred from the teacher to the learner. Learners have to develop concepts and ways of reasoning themselves. They can be supported by the learning environment teachers offer to them: supply of information and experiences that are relevant to concept development, discussions about meanings.

Results from research tell that science education is not very successful in concept formation. Pupils do learn to use scientific words, but the meanings attributed often are very different from the accepted science meanings. That becomes overt in the conceptual difficulties learners meet: many pupils do not give the desired answers to questions that ask for conceptual understanding. They appear to stick to concepts and ways of reasoning that come from daily life experiences.

In this paper, it is described how student teachers can be sensitised to the learners' ways of reasoning, in order to use pupil thinking in a productive way, as a start for authentic physics learning. The same way goes for science teacher educators. If they want their student teachers to get sensitive to pupils' ways of reasoning, they, in turn, have to listen carefully to their student teachers when they explain their views on teaching and learning science. This doubling idea is called the congruence principle (Korthagen 2001).

The research methods used in the study reported here, are grounded in this principle. The central issue of the study is to identify the effects of tasks, in a succession from simple to complex teaching situations, that on the one hand promote the development of student teachers' sensitivity to pupils' ways of reasoning and on the other inform teacher educators about student teachers' ways of reasoning.

Theoretical framework

In spite of being acquainted with scientific ideas and concepts and having learnt to apply them, learners often stick to daily life ideas. This may be due to the fact that science education tries to replace 'wrong' ideas by 'sound' scientific concepts, without having learners experience what is wrong in their ideas and why new concepts are needed. To most secondary school pupils counts that science comes up with solutions to problems that they are not yet aware of. Therefore, they are not challenged or motivated to go deeply into science ways of reasoning (Vollebregt, 1998).

It is well known that even academic physics students hold alternative ideas that are comparable to the ones that are found with secondary pupils (Viennot 1979). With academic students, those ideas are covered by a thick layer of very abstract and formal subject matter. That may be why they are not aware of their basic conceptual problems. However, when becoming a student teacher, they have to return to the basics of the subject. Then, the conceptual problems become manifest again (Reinke 1997; Oldham *et al.* 1999; Frederik 1999).

The issue of alternative conceptions cannot be tackled by ignoring the learners' ideas. On the contrary, their reasoning should be acknowledged and discussed with them. That will provide a driving force to concept development. A main task to method courses in science teacher education is to show what learners' ways of reasoning may look like and to provide student teachers (STs) of experiences that help them to bring about changes with the learners. Moreover, STs' ideas about science itself, about teaching science and about teaching in general should be challenged. Many of them have a transmission view on teaching and they are inclined to reject daily life ideas as 'incorrect' and to simply replace them by the 'right ones'. To challenge these ideas of teaching, STs need experience that pupils' ideas are authentic productions that can be regarded as valuable and necessary to the development of scientific ideas.

In this study we focused upon the increase of pedagogical content knowledge (Shulman 1986). As teacher educators/researchers we learnt a lot about 'teaching pedagogical content knowledge': how to guide student teachers. The idea of congruence between learning of pupils, student teachers and teacher educators is the core of our method.

Context of the study and methodology

This study was done in the context of teaching a Science and Mathematics Teacher Orientation Course (van der Valk 1996). In particular a series of activities with increasing complexity were studied:

a. at the start of the course, participants prepared a lesson (lesson preparation method, van der Valk and Broekman 1999) and discussed with peers

b. half way the course participants taught one to one lessons to individual pupils (Vedder, 1984), transcribed a small part of it and discussed it with peers and wrote a reflection
c. at the end of the course, participants did in trios a teaching practice in a school. They taught a series of some six lessons, one lesson was observed by a teacher educator

Data were gathered in different ways: interviews and student notes (a.), transcriptions and reflection reports (b.); reflection reports and teacher educator's observation and review notes (c.).
Data were analysed looking for STs' own conceptual difficulties and ways of dealing with pupils' alternative conceptions.

Research questions:
1. What activities resulting in accounting for pupil thinking do starting science student teachers undertake when preparing a lesson?
2. In what ways do student teachers react to alternative pupil conceptions in one-to-one teaching situations?
3. In what ways do student teachers show sensitivity to pupil thinking when teaching their first lesson series?

Results 1: accounting for pupil thinking when preparing a lesson

From student teachers doing the lesson preparation assignment, being interviewed about it and reporting about their lessons to their peers, four activities that resulted in accounting for pupil thinking were found:
1. recalling the own learning experiences in secondary school
2. recalling out-of-school learning experiences
3. using their preliminary experiences as a teacher (e.g. of private lessons, homework classes)
4. discussing the actual conceptual problems the STs showed themselves

Here, examples of the first and fourth way will be given.
By recalling the own learning experiences as a youngster, STs made explicit their former reasoning as a pupil. That resulted in using them in the lesson. This can be illustrated with the following case:

> **Bastian's case: remembering a challenging question**
> Bastian was preparing a physics lesson about expansion to 8th grade pupils. After having told about expansion of metals by heating, he would show a metal plate with a circle hole cut out. He planned to ask his pupils: *what will happen to the area of the hole when the plate is heated*? They would have to discuss in groups and he expected 'heated discussions'. Next, he would review the group answers and identify the right answer.
> In the interview he explained that his former teacher had asked this question and that he had argued that the iron would expand in all directions, making the hole smaller. He was then surprised to learn that his conclusion was wrong: the hole area would increase. He had got convinced, however, by the argument that the cut out circle, being heated, would expand as well so that it would fit exactly into the hole.
> In addition to what his former teacher did, Bastian planned to show the cut-out circle part of the plate. Thus, he would provide his pupils with a scaffold for understanding that the hole would expand by heating, using the argument that had convinced him.

This case shows that remembering details of the own learning process (solving a conceptual problem, answering a challenging question) can result in accounting for pupil thinking. It is remarkable that STs that used such memories generally did not plan to explain, but to have pupils do activities that make them aware of a problem or a challenging phenomenon and provide them with scaffolds to solve or understand it.
When presenting their lessons to peers, some STs showed conceptual problems that they were not aware of. Some of their peers noted them. By the discussions that followed, the problems were solved and the STs got aware that they had to understand science as well as alternative ideas to identify conceptual problems and help pupils to solve. This can be illustrated with an example.

> **Annie's case: becoming aware of a conceptual problem**
> When presenting the lesson she prepared, Annie showed to hold the idea that the steam above boiling water is hotter than the water itself, by saying that the temperature of the water is 100 ^{o}C and the steam is 120 ^{o}C. Her peers asked why she thought so. By that, she discovered her error.
> The teacher educator indicated a possible underlying idea: heating always results in a change of temperature, even with a phase transition. If pupils hold this idea, the difference between heat and temperature cannot become clear to them. All STs were asked to look at their own prepared lesson to see if they themselves had suggested this idea in their lesson. Most of them discovered they did, e.g. by omitting to pay attention to phase transitions. Some even had planned to explicitly use this 'rule', without realising that it is not a general one. The STs realised: if you don't have a clear idea of a concept, you might promote 'misconceptions'.

Results 2: accounting for pupil thinking when teaching a one-to-one lesson

Teaching one-to-one lessons, student teachers were confronted with authentic pupil thinking. In order to recognise pupil ideas and study the way they themselves reacted to those, STs were asked to make a transcription of a part of their lesson that may show pupil thinking and how they dealt with it in the lesson. Those transcriptions were discussed in the class.
Analysing the transcriptions, four kinds of reaction to pupil thinking were found.
First: rejecting pupil's contribution. STs were inclined to immediately rectify pupil responses that they found irrelevant or incorrect. Starting with the word 'but', they reacted to those answers by giving the 'correct' explanation. In many transcriptions it was possible to point to the effect of the rejection: the pupil stopped giving contributions.
Second: ignoring pupil's contribution to the teaching-learning process. STs did so because of diverse reasons, e.g. simply not hearing it (until reviewing the audiotape) or being surprised about an unexpected answer and not knowing how to react. The effect of ignoring was quite often a deterioration in the atmosphere of the lesson, apparently because pupils concluded that the ST was not interested in what they said.
It is clear that these two reactions did not add to getting sensitive to pupil's reasoning. However, identifying these reaction in a transcription and discussing its effects did.
Third: acknowledging pupil's contribution by expressing to hear what their pupil say, to appreciate their contribution and to like to know more about their thoughts. That appeared from e.g. repeating pupil's words, recapturing or by asking questions. This generally resulted in pupils explaining their thoughts, so that the STs could account for their thinking in their explanations. It also resulted in a good atmosphere during the one-to-one lesson. This is illustrated by the following transcript that was presented by a ST.

Andrew's case: acknowledging by keeping asking
Andrew helped Lia with a question from the textbook about the weight of air.
1 Andrew *So the question is: does an inflated ball becomes lighter when you let the air flow out?*
2 Lia *No*
3 Andrew *Why do you think so?*
4 Lia *Well, I once kicked a plastic ball into the pond and it kept floating. And so did a leather ball*
[Andrew kept asking; at last, Lia said]
5 Lia *But it does not weigh, air, does it?*
6 Andrew *Air does not weigh?*
7 Lia *Well, surely it does? Doesn't a leak ball weigh more than a full one, when you put it on the scales, or does it?*
8 Andrew *Well ...*
9 Lia *That is the idea I have, I mean, when I kick a leak ball, it is heavier than when I kick a normal one*

Andrew showed being interested in what Lia meant: he kept asking (3), repeated her words (6) and stimulated her in verbalising by not immediately giving the answer to questions. That is why Lia felt acknowledged. It is interesting that she herself suggested a decisive activity for checking her idea: let us use the scales!
When his transcription was discussed in the class, Andrew was surprised to hear that Lia's idea was documented with other pupils as well (Driver et al., 1985). In class discussions like this, the focus was not only upon understanding pupil thinking. Even more important is the question how a teacher can manage the pupil explain his/her thoughts. That is why the teacher educator pointed at interview techniques that the STs used and its effect on pupil learning.

Fourth: anticipating to pupil ideas. Some skilled STs anticipated in their 1-1 lessons on relevant pupil ideas in such a way that pupils are stimulated to discuss them. That shows that those STs were already sensitive to pupil thinking.

Results 3: accounting for pupil thinking in school practice

In the second half of the Orientation Course, student teachers had school practice in groups of three. At the end of it, each taught a series of five to six lessons to a group of lower secondary pupils. Their peers observed the lessons and so did the mentor teacher. The lessons were reviewed with the peers and the mentor teacher and

logbooks were written. If possible, the teacher educator attended one of those lessons, participated in the reviewing and gave some comments on the logbooks. STs finished their teaching practice by writing a reflection report.
Just like in the one-to-one lesson situation, in classroom teaching four ways of reacting to pupil thinking were found: rejecting, ignoring, acknowledging and anticipating. In this section, it is focused upon acknowledging and anticipating as those are ways STs account for pupil thinking. In plenary teaching situations, different ways of these reactions were found. Rejecting and ignoring are not dealt with.

acknowledging pupil thinking in the classroom

Acknowledging in a classroom situation is much more complex than in a one-to-one situation, as not only the effect on the individual, but also on the group has to be taken into account.
Acknowledging pupil reactions of surprise about phenomena they saw, about explanations or about a new view on well-known things was found in many student teacher lessons that were observed by us as teacher educators. That reaction is relative simple because the question of correct or incorrect is not at stake.
However, if pupils explain alternative ideas, acknowledging pupil ideas in the classroom is very difficult to STs. For, they fear that pupils will feel affirmed in their incorrect ideas. So they are inclined to ignore the ideas or to reject them and tell the 'right' ideas. Doing the school practice, STs are encouraged to observe how their mentor teacher copes with this problem. A ST wrote in her logbook:

> *The mentor teacher asks a question. A pupil answers. The teacher asks the other pupils whether or not they agree. She asks a disagreeing pupil for his opinion. Asks again who (dis)agrees. In the same way a third opinion appears. In this way, pupils are stimulated to contribute and so they do.*

So by observing the mentor teacher, STs can learn how to acknowledge pupils' thinking in the classroom without affirming incorrect ideas, but challenging them to discuss.

anticipating to pupil thinking in the classroom

We found some wonderful ways of anticipating to pupil thinking.
First, anticipation based on observations. Some STs happened to have the opportunity to observe a class in which a lesson is taught that they had to teach themselves within some days. They focused on pupil thinking and were able to identify one or more pupil ideas.

> **Annie's case: melting and solidification point**
> Annie observed a lesson about phase transitions. The teacher demonstrated that candle wax solidified at a certain temperature, the solidification point. In an experiment, the pupils determined the melting point of candle wax. In her diary, Annie noted about this lesson *pupils found it very curious that the melting point is at the same temperature as the solidification point.* She was surprised, for it was so self-evident to her. When teaching the lesson herself, she listened closely whether or not the same wonder appeared in her own class. She found out it was.

Second: trying out the presence of alternative ideas in the classroom. STs often find it hard to believe that a naive pupil idea found in literature or told by the teacher educator, is present in their class. When trying out, they were surprised to find that it was really there. But it brought about a problem that they had not thought of: how to convince pupils that they have to change the idea?
Third: reflection on experiences, followed by anticipation. Some STs noticed in the classroom that pupils had difficulty in understanding a topic. Just by reflection on the lesson, they could identify the alternative idea that caused the problem. And next lesson they returned to the topic, stimulated pupils to explain the difficulty met and tried to solve it.

> **Bert's case: reflection and anticipation**
> Bert's pupils were measuring the temperature of water being heated on a bunsen burner until boiling. They had to make a graph afterwards.
> One pupil tried to measure the temperature of the flame: the thermometer broke. Some time later, Bert remarked that a group of girls was discussing heavily: the water was boiling; did they have to do more measurements or not?
> Reflecting on the lesson afterwards, Bert wrote in his logbook: *not all students understand that there is a highest point (100 ^oC) when boiling water. I'll have to come back on this.*
> Next lesson he asked, among others, the group of girls to draw the diagram they made on the blackboard. Later, in his logbook he wrote: *using the diagrams drawn on the blackboard we were going to look what happened when the water was at 100 ^oC. Some knew that this was and kept the highest point, others thought the thermometer would break if continuing heating and measuring. I have explained that it is not the case.* The point in the girls discussion was the thermometer would break!

Conclusions and recommendations

The issue of this paper was the question how to make student teachers sensitive to pupil thinking and reasoning and how to become sensitive to student teachers' reasoning as a science teacher educator.
As an answer to the first research question of this study, four activities were found that resulted in accounting for pupil thinking:

1. recalling the own learning experiences in secondary school
2. recalling out-of-school learning experiences
3. using their preliminary experiences as a teacher
4. discussing student teachers' own actual conceptual problems

As an answer to the second research question, four ways of student teachers' reacting to pupil contributions in one-to-one lessons were found: rejecting, ignoring, acknowledging and anticipating. However, only the latter two appeared to contribute to accounting for pupil thinking.
As an answer to the third research question, acknowledging and anticipating were found as ways of accounting with pupil ideas in the classroom as well. An important activity that STs did was observing the mentor teacher and peers how they deal with pupil ideas. Moreover, trying out whether or not a particular pupil idea was hold by the pupils, reflecting on experiences in order to identify student reasoning appeared to be ways in which anticipating in classroom situations was possible to starting STs.
It is recommended to deliberately promote STs in doing the activities found: recalling the own learning problems; discussions about actual conceptual difficulties; listening carefully to what pupils say etc.
It is helpful to make the learning situation of the STs gradually more complex, as was done in our orientation course. However, recent developments influenced by a shortage of teachers, like in-service education of starting teachers, prevent that it can be applied systematically. How to apply the results of this study to in-service student teachers still is a question to be answered.

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