

What Research can Contribute to the Improvement of Classroom Teaching

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1. Introduction: Areas of research in physics education

Research in physics education can be seen in the following three areas:

- **physics education
from the viewpoint of physics**
 - new experiments
 - use of computers
 - working on new and better explanations of (modern) physics ("elementarisation")
- **physics education
from the viewpoint of students' learning**

(see details on next page)
- **physics education
related to history and philosophy of science**
 - epistemology of physics compared to everyday life thinking
 - epistemological beliefs of students
 - historical analysis of the development of theories
 - teaching strategies using epistemological issues and history of physics
 - epistemological analysis of learning

The first area - physics education from the viewpoint of physics - has a long tradition especially in Germany. We also in Bremen do some work in this area in the field of quantum physics and the use of computers in physics education, but the main focus of my paper will be the second area: physics education research from the viewpoint of students' learning. In the

third field, physics education related to history and philosophy of science, research has increased in the last ten years. I will only make some short remarks on that topic.

Within the field physics education research from the viewpoint of students' learning I see five different types of investigations:

- **physics education research
from the viewpoint of students' learning**
 - Empirical investigations on students' alternative frameworks in mechanics, electricity, atomic physics, etc.
 - Empirical learning process studies
 - Theoretical investigations about physics learning (constructivism, cognitive view, system theory)
 - Teaching strategies, based on research
 - Curriculum materials, based on research

Here the first part is perhaps the most widely developed and best known part of research: empirical investigations on students' alternative frameworks in mechanics, electricity, atomic physics, etc. This has been a research tradition now for more than 20 years. There are a lot of results from this research tradition from all over the world which are important for the improvement of classroom teaching. The second part in the list, empirical studies of learning processes, has developed more recently. For me this kind of research in a natural way develops from the first one: after knowing about students' alternative frameworks with which they come to start learning physics, it seems to be the logical next step to investigate their pathways and processes from their initial alternative views to a more scientific view. The third part, theoretical reflections on learning from a constructivist view, is perhaps very crucial for physics education research to come to a more sophisticated level. Finally with respect to the fourth and fifth type of research mentioned above I will give some examples of teaching strategies and curriculum materials based on research.

2. Results of empirical research on alternative frameworks of students

This is the most developed field of empirical research in physics education. There are quite a lot of empirical studies done all over the world in this field, and methods and results of these studies have come to converge, so by now a body of secure knowledge has developed on which further research work and teacher education and development of curriculum materials and teaching strategies can be based.

The following table shows a list of the numbers of studies on students' alternative frameworks in different fields of physics shown by Duit in his bibliography (Table 2).

This list shows a high number of studies e.g. in the field of mechanics, electricity and others. It shows small numbers e.g. in modern physics, and there are no studies at all listed in a field which we in Bremen think is very important: empirical studies on epistemological beliefs of students. (c.f. Meyling 1990, Niedderer et. al. 1992, see also special issue (9) of JRST 1991). So altogether empirical investigations on students' alternative frameworks have developed to a high standard, and the results of this field can be brought to the improvement of classroom teaching and teacher education. The question, of course, remains: how to make use of the results. It is a question of contents in teacher education but also, and perhaps more difficult, of processes how to come to some kind of conceptual change of teaching in the mind of teachers. How can we communicate with teachers, and how can we include those results into teacher education.

To give some examples of results I start with a more general thesis developed in our group in Bremen: The structure - not the content - of everyday life thinking is principally different from the structure of concepts and theories in physics. This, in our view, is the deeper reason of the differences between alternative frameworks and scientific thinking. This general result has got strong support in a paper from Reif and Larkin (1991).

The idea of a general structural difference was developed out of theoretical and empirical results (Schecker 1985, Niedderer 1987), triggered by a paper of the German philosopher G. Böhme (1981) on the relation between science and (everyday life) experience. The paper of Reif and Larkin (1991) contains similar ideas about differences of cognition in scientific and everyday domains. Both views have one central focus in common: difficulties of learning science are seen as a consequence of different

goals in both domains. These different goals create different viewpoints and lead to different meanings for the same terms or concepts.

Topic	# entries	Topics
Mechanics	281	Force and motion/work, power, energy/speed, acceleration/gravity/pressure/density/floating, sinking
Electricity	146	Simple, branched circuits/topological and geometrical structure/models of current flow/current, voltage, resistance/electrostatics/electromagnetism/danger of electricity
Heat	68	Heat and temperature/heat transfer/expansion by heating/change of state, boiling, freezing/explanation of heat phenomena in the particle model
Optics	69	Light/light propagation/vision/color
Particles	60	Structure of matter/explanation of phenomena (e.g. heat, states of matter)/conceptions of the atom/radioactivity
Energy	69	Energy transformation/energy conservation/energy degradation
Astronomy	36	Shape of the earth/characteristics of gravitational attraction/satellites
Modern Physics	11	Quantum physics/special relativity
Chemistry	132	Combustion, oxidation/chemical reactions/transformation of substances/chemical equilibrium/symbols, formula/mole concept
Biology	208	Plant nutrition/photosynthesis/osmosis/life/origin of life/evolution/human circulatory system/genetics/health/growth
Table 2: Studies on Students' Conceptions in Different Areas (the figures give the number of articles contained in the present edition of the bibliography in a certain area)		

(Pfundt, Duit, 1991, xli)

The main goal in the everyday life domain is "to cope satisfactorily with one's environment, leading a good life" (R)² and "to solve problems in specific single situations" (N). This is done by "few (and short) inferences with various acceptable premises, based on rich compiled knowledge, with locally coherent knowledge" (R), with

² We will refer to the paper of Reif and Larkin with (R) and to our table 1 (below) with (N)

concepts, which "are vague in general but with a sharp and clear meaning in a special context" (N). This "indexicality" goes back to the work of Böhme (1981, p.90, 94) ³:

"The 'indexicality' of pre-scientific concepts means precision (in the context) and vagueness (in relation to different contexts). The first step towards science cuts off the relationship to specific contexts and leaves only the vagueness. Science creates its own precision systematically after this step."

"Everyday life experience gets this kind of vagueness only by cutting its relation to the everyday life context. The residuum of this isolation, the 'pure quality', is vague because it exists in everyday life in different contexts."

Experience is related to concrete specific situations and so the meaning of concepts in everyday life is context-bound. 'Force' in the everyday life domain is always a special force, bound to the special context ('weight force', 'spring force', 'motor force', 'force of a moving car') whereas physics defines Newtonian force in general terms for all situations by its relation to changing movement, i.e. to acceleration. 'Force' gains its sharp meaning in the physics domain by being embedded into a conceptual network of the theory of mechanics.

The main goal in the scientific domain is "optimal prediction and explanation with maximal generality, parsimony, precision, consistency" (R). This formulation relates to the goal to create "special theoretical knowledge which parsimoniously permits inferences about the largest possible number of observable phenomena, on the basis of a minimum number of premises" (R). In our formulation the main goal of science is "to construct general theories that explain and predict many single events by a small set of general rules" (N). This stresses the fact of wide applicability of concepts and relations, which "are defined sharp and general" (N). For us the goal of constructing general theories is central, and we see the meaning of generality precisely equivalent to the principle of parsimony: universal concepts and relations are created with a goal in mind to allow for many inferences on the basis of few sharply defined concepts.

³ Translation from German: HN

	Everyday domain	Scientific domain
Domain goals		
<u>Main goals</u>		
Central goal	Leading a good life	Optimal prediction and explanation
Subgoal	Adequate prediction and explanation	
Requirements	Adequate generality, parsimony, precision, consistency	Maximal generality, parsimony, precision, consistency
<u>Working goals</u>		
Understanding	Few inferences Various acceptable premises	Many inferences Well-specified premises
Assessing validity	Moderate importance Various acceptable premises Plausible inference rules	Central importance Observation-based premises Well-specified inference rules
Domain cognition		
<u>Knowledge structure</u>		
Concept specification	Implicit and schema-based	Explicit and rule-based
Knowledge organization	Locally coherent Associative organization	Globally coherent Logical organization
<u>Methods</u>		
Problem solving	Short inferences based on rich compiled knowledge	Long inferences based on parsimonious knowledge
Types of methods	Non-formal	Complementary formal and non-formal
<u>Quality concerns</u>		
Quality control	Non-formal	Strict and explicit
Efficiency	Naturally efficient for everyday tasks	Designed for efficiency in complex tasks

(Reif, Larkin 1991, p. 737)

So, in science we have generally defined concepts whereas in everyday life we have what we call "cluster concepts". That means concepts like force or heat or current in everyday life have a vague meaning in general but defined sharply in the special context. This has to do with the aim of everyday life. Here we are interested in solving special problems in specific situations. Nobody in everyday life is interested to solve

problems for all possible situations or all situations you can think of. You want to solve this problem or this other problem, and therefore you don't need generally and sharply defined concepts as in science. Everyday life concepts have a sharp meaning only in the context of a special situation.

The following frame (on the next page) shows an overview of related empirical results on students' "matrix of understanding (MOU)" on a first level:

I. Students' General Frames of Thinking in Physics
(c.f. Schecker 1985)

1. Students believe, that the task of physics ... is to explain everyday-life experience exactly and in single concrete specific situations, with every detail being important.
In contrast, physics is more interested in general concepts relevant for a big wide variety of situations (parsimony). Physics is interested in a single situation only as an application of a general structure.
2. Students tend to organize their experience in episodes.
They tend to think
 - in concrete realizations of theoretical "pure" events
 - in analogies
 - in context bound "subjective areas of experience"(Bauersfeld)
3. Students use thinking strategies from the everyday-life world.
They tend to think
 - in properties (not relations)
 - in activities ("experimental gestalt of causation", Andersson)
 - in final purposes
4. Students look upon physics as a body of formulas, rather than a perspective of the world.
 - They take formulas as rules for computing, not as a language for physical concepts.

The following frame shows some general results on students' "matrix of understanding (MOU)" on a second level related to interests:

II. Some selected interests of students in physics:

1. Students are interested to investigate single phenomena.
An example is interesting for itself, not only as an application of a general concept.
2. Students are interested to do own laboratory work.
3. Boys are interested in technical applications and technical questions. Often they are interested in physics only because they don't distinguish between physics and technics
4. Girls are interested in natural phenomena like the motion of the planets and the moon.

A very well-known result of empirical research in mechanics is an alternative meaning of the concept force. Some researchers tend to describe the students' ideas as confusing force and energy or force and momentum. In our view this is no confusion but a different structure of thinking as discussed above. It is a different style, a different kind of using concepts. Force in everyday life is a general cause of movement

or action, and this develops a special meaning in the special context of a situation which then can be analyzed being similar to energy or to momentum or to a Newtonian or to an Aristotelian meaning of force. It is a context-bound meaning. The following frame shows some general results on students' "matrix of understanding (MOU)" in a third level related to precepts:

III. Overview of selected precepts of students in physics:	
1.	Mechanics
-	force/energy as a cluster concept
-	acceleration as a <u>result</u> (v), not as a <u>process of change</u> (dv/dt)
-	velocity as speed (not a vector)
2.	Electricity
-	charge, current, voltage, energy as a cluster concept
-	the notion of current consumption
-	students' representations of the topological structure of circuits
3.	Heat
-	heat and temperature as a cluster concept
4.	Atomic physics ⁴
-	orbit - probability - orbital - state - energy level as a cluster concept
-	Special conceptions about "model", "energy level", "probability"

In electricity there are similar effects. You have a cluster concept "current" which explains the brightness of bulbs or what you pay on your bill, or the strength of batteries. It thus contains aspects of charge, aspects of physics meaning of current and movement, aspects of energy. This alternative concept "current" thus is far away from having a narrow and precise meaning only of rate of flow or describing only the movement of electrons. It has a meaning like fuel or substance also. From this alternative meaning of current the meaning of flow is more like flowing to a bulb instead of flowing through a bulb. In quantum physics we see a similar situation where orbits and orbitals are used interchangeable in different contexts.

Some more specific findings tell us something about the relation between force and movement. Students, for instance, tend to think that "motion has force". This, in our mind, is related to a meaning of force like energy, but it would be wrong to say students confuse force and energy. Their views of the concept force is different. Another finding is: We have always force in the direction of the movement. The following frame gives an overview of those results related to the precept "force":

⁴ see Appendix 1

The cluster concept 'force' (c.f. Schecker 1985)

The word 'force' is used in a great variety of physically different, context-bound meanings:

- Newtonian force
- momentum
- potential and kinetic energy
- torque, time integral of force, etc.

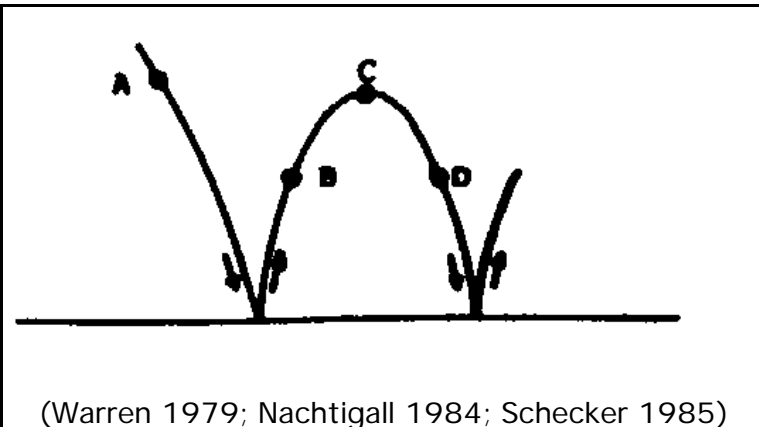
This indexicality or vagueness is a power of everyday life concepts. It enhances communication in these contexts. The concrete meaning only sharpens out in a concrete context where the student uses 'force'.

Students do not simply take the same word to denominate concepts that they implicitly distinguish.

Some more specific findings:

- A moving body has force.
- There is always force in the direction of movement.
- When a body is set into motion, the mover transfers force to the body.
- When two moving bodies collide they exchange forces.
- Only active, e.g. living or moving bodies can exert real forces.

The following picture shows a famous example. The most interesting question is: What kind of force do you have in point C?



With this task even advanced physics students sometimes have difficulties. Their typical answer is a force in the horizontal direction which is due to the alternative frameworks listed above.

I often had a lot of fun with this example in my course "theory development in physics" for teacher students.

There are many results, especially of students' alternative frameworks in mechanics where many researchers all over the world agree on methods and results of studies. This is an important fact for the development of physics education as a discipline. It means that there is a secure point to build on for necessary changes in classroom teaching. In mechanics many researchers have contributed to the present state of the art: Nachtigall, Jung, Schecker in Germany; Viennot in France; Watts and others in

England; McDermott, Clement, and others in USA. This is especially important because, in education, you will often have a feeling that nothing is true and nothing is wrong. So, having a basis of results like in the area of alternative frameworks, is a very important fact. There are agreed results.

In spite of all these results there is a need for a compendium or handbook of students conceptions. The bibliographies of Pfundt and Duit (1992) or Carmichael et.al. (1990) give some help to find good review articles and research papers.

3. Research Results from other Areas

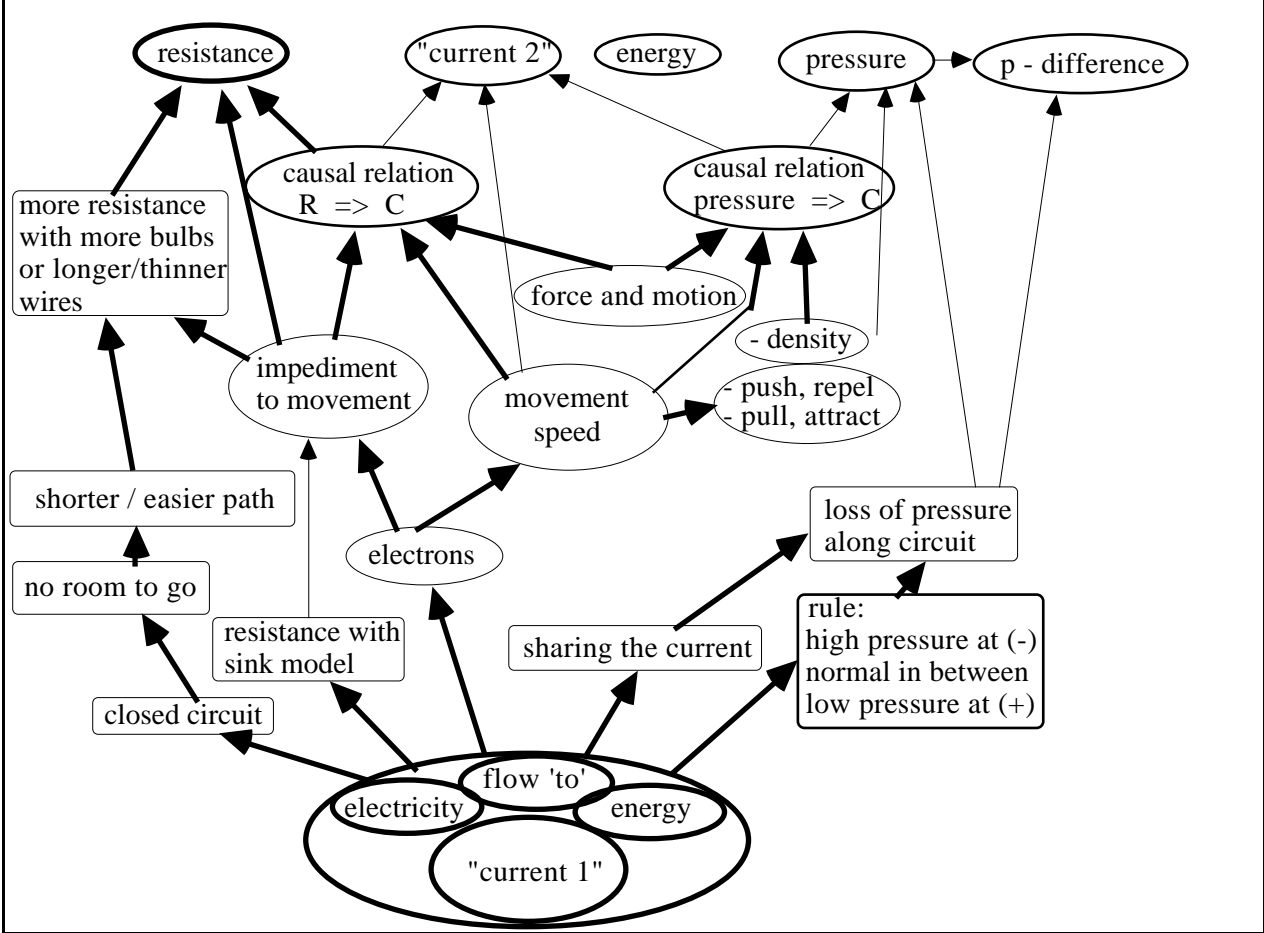
3.1 Research in physics learning

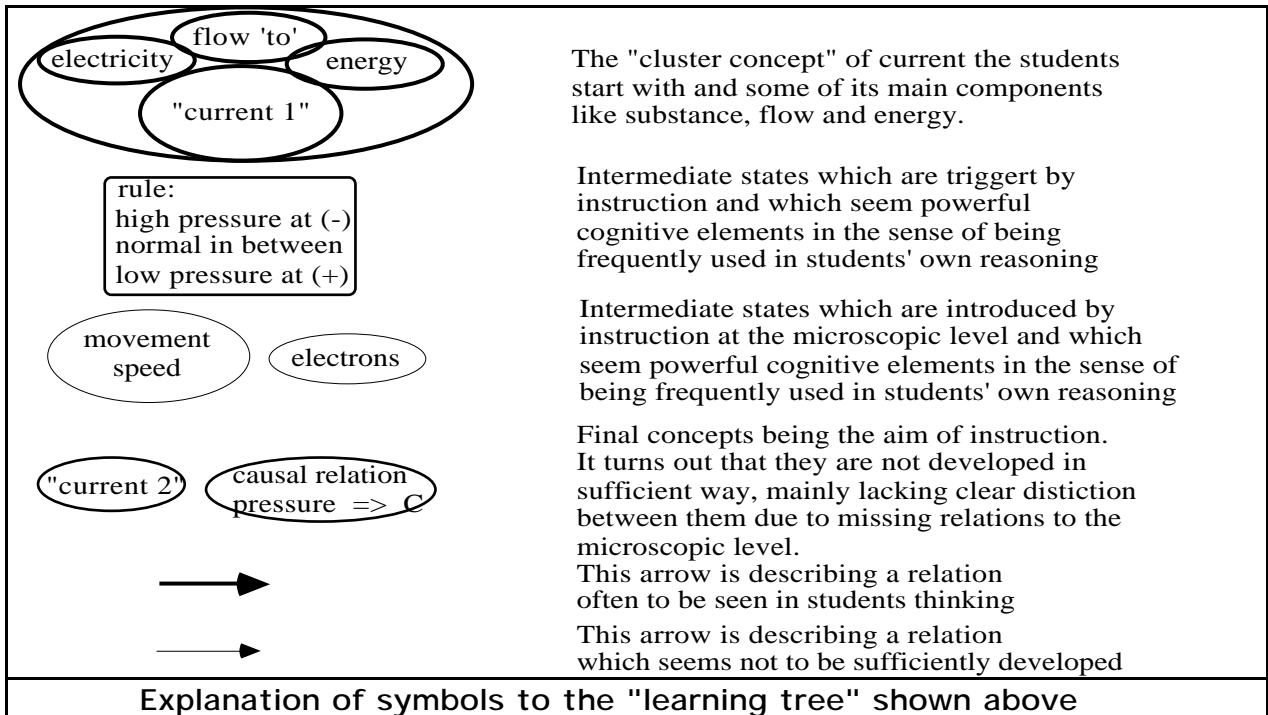
With respect to empirical investigations of learning processes I refer to the international workshop on "Research on Physics Learning - Theoretical Issues and Empirical Results" held in Bremen in 1991 (Duit, Goldberg, Niedderer (eds. 1992⁵). As a result of discussions during this workshop participants agreed that it is very important to analyze students' pathways of learning in any domain which is important for physics teaching. The general hypothesis is: there are content-specific steps of learning, marking the way from the alternative view to the science view which are more or less independent of the way of teaching. The notion is that the learning process is not going from the alternative view directly to the scientific view but going through a series of intermediate states.

An example of this kind is the following diagram on the next page:

⁵ These proceedings can be ordered from the IPN in Kiel. Address see end of this paper.

Development of the cognitive system "Electric Circuits" during a learning process of three college students ("learning tree") (Niedderer 1993)



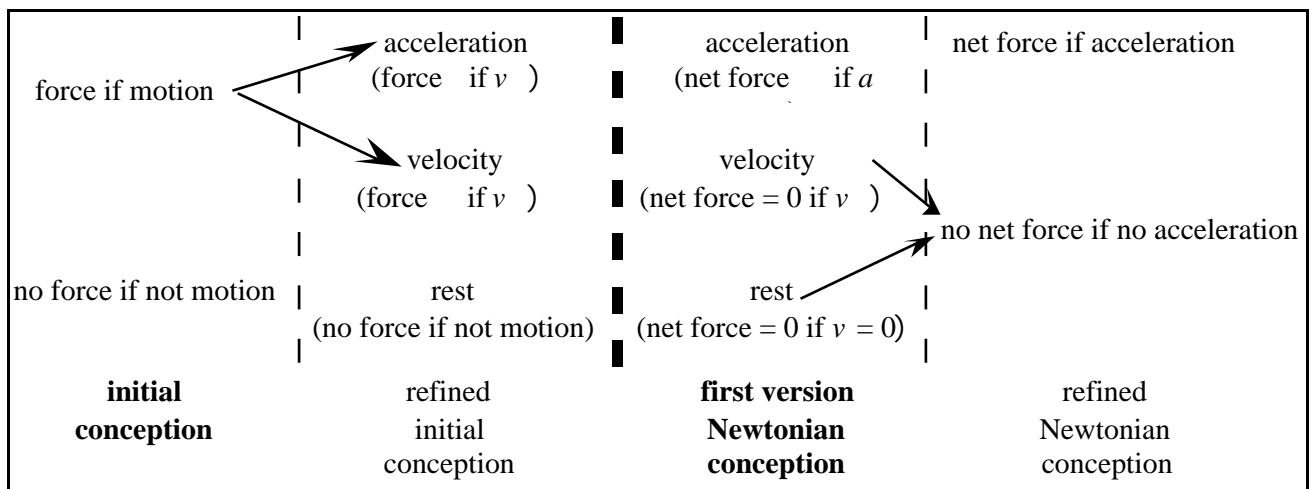


This picture shows an attempt to demonstrate the cognitive changes which took place during a learning process of twelve hours in the field of electric circuits. You can see it as a "learning tree" showing how new cognitive elements grow out from the basic alternative view of a cluster concept "current 1", shown at the bottom of this picture. This concept is what the students start with in the learning process. The upper part shows the scientific concepts which are the aim of the course. In between there are a lot of "intermediate" stable cognitive elements.

Many of these cognitive elements are very well known from previous investigations on students' conceptions in electric circuits. For instance, the element "sharing the current". It is a more sophisticated version of the well-known current consumption conception which seems to be even more stable and effective. It says that the current is shared by several bulbs, for instance, no matter whether they are in series or in parallel. Another very well-known cognitive element is the "sink model" which means that students think of the current going to a bulb or resistor and no thought is given to the question whether the current comes out again. The interesting fact, however, in this learning study is that those cognitive elements get a new meaning during the learning process. For instance, the element "sharing currents" is also used in connection with voltage or pressure ("sharing the voltage") and this, of course, in

some cases gives very good results. Other elements in this picture are new; for instance, all elements in the middle are related to force and movement of electrons giving a related new meaning to current, resistance and voltage. In this case, some well-known alternative conceptions from mechanics related to these cognitive elements help the students to develop a scientific correct view in electric currents: the Aristotelian view held by many students in seeing a causal relation between force and speed gives a scientifically correct explanation! The bigger the force the higher the speed, this is true in electric circuits! This might be one reason for the result I got from this interpretive research that this microscopic view gets a lot of resonance in students' thinking. This idea of electrons and their relation between force and speed seems to help students more with their own explanations of current and voltage than the intended idea of pressure and pressure difference.

Another example of an intermediate state is given by Dewey Dykstra (1992). On the left side of this diagram you can see the well-known preconcepts of force and motion. On the right side you can see the intended scientific concept of Newtonian force and acceleration. In between you see two different intermediate states coming to the correct relation between force and acceleration in two steps. This is a kind of stroboscopic picture describing the cognitive state of students at selected times:



Dykstra (1992, p. 44): A series of conceptual changes.

3.2 Theoretical results from a constructivist perspective of thinking and learning

As a starting point I take a formulation from Stefan von Aufschnaiter (1991) about the learning process: "The learning process has to be seen as a process of self-development of the cognitive system of the learner". This means that a transmissive

view of learning bringing correct scientific theories and concepts directly from the teacher to the learner is denied. Instead of this we see the learner as actively constructing his own new concepts, constructing his own meanings for what comes from outside his mind (texts, statements from teachers and other students, experiments), actively deciding what is of interest for him, what he takes out of statements or texts, or what he leaves aside, what observation he sees in an experiment and what he doesn't see, what he is interested and what he is not interested in, and so on. By this process the student himself constructs his own concepts and his meaning for these concepts. "Language therefore cannot transfer concepts from one person to another, it can only call up in the listener the representation of the experiences that the listener has made with these concepts." (von Glasersfeld 1992) So the function of language in the teaching process is not to transmit concepts and their meaning from teacher to student but to have a means of discussing and negotiating about the differences in the constructed meanings of students and teacher.

I shall give examples of new teaching strategies based on research and new curriculum materials based on research later in this paper (part 5).

4. General Consequences for teaching

New aim: teaching physics for understanding

The aim of teaching physics so far was oriented towards solving quantitative calculation problems, it was related to the use of formulas. From this point of view teaching was more or less successful and effective. Teachers got quite good exams and students got good marks. Students managed to work with formulas in a limited set of quantitative problems, although they perhaps did not understand the meaning of the concepts, used in the formulas. Further research showed, however, that the same students asked with different questions probing their qualitative understanding of these formulas and concepts showed that they didn't really understand, that they had alternative ideas about those concepts, more related to the everyday life view, no matter whether they had good or even excellent marks in physics.

In this situation we have to ask ourselves how we see the priority of aims in physics teaching. We have to decide whether quantitative problem solving is more important than qualitative understanding of physics concepts, or less. Perhaps we have to make different decisions for different groups of students. It may well be the case that for

physics majors the ability to calculate quantitative problems is most important. But for education in general it might be more relevant that people understand the different nature of concepts in physics and how physics uses them. People perhaps should at least understand the difference between everyday and scientific meaning of concepts. For me this would be enough, I do not claim that people who do not specialize in physics should always use concepts like a physicist does. I do not intend to make every student a physicist. This is not possible anyway, and it is not necessary at all. It might also be boring.

New aim: "Teaching Physics for Understanding"

- Traditional aim of physics teaching:
Problem solving, quantitative formal reasoning
- New aim of physics teaching:
Qualitative conceptual understanding

Empirical studies about students' understanding of force and motion, electricity or heat and temperature show that even after physics instruction students tend to use their pre-instructional concepts instead of physical concepts and principles.

Haertel (1990) draws the conclusion that formal mathematical and physical knowledge without a qualitative understanding of basic concepts and relations does not help the student to solve new problems.

Science experts engage in qualitative reasoning before they start a quantitative formal approach (Chi, Feltovich & Glaser, 1981; Reif, 1987).

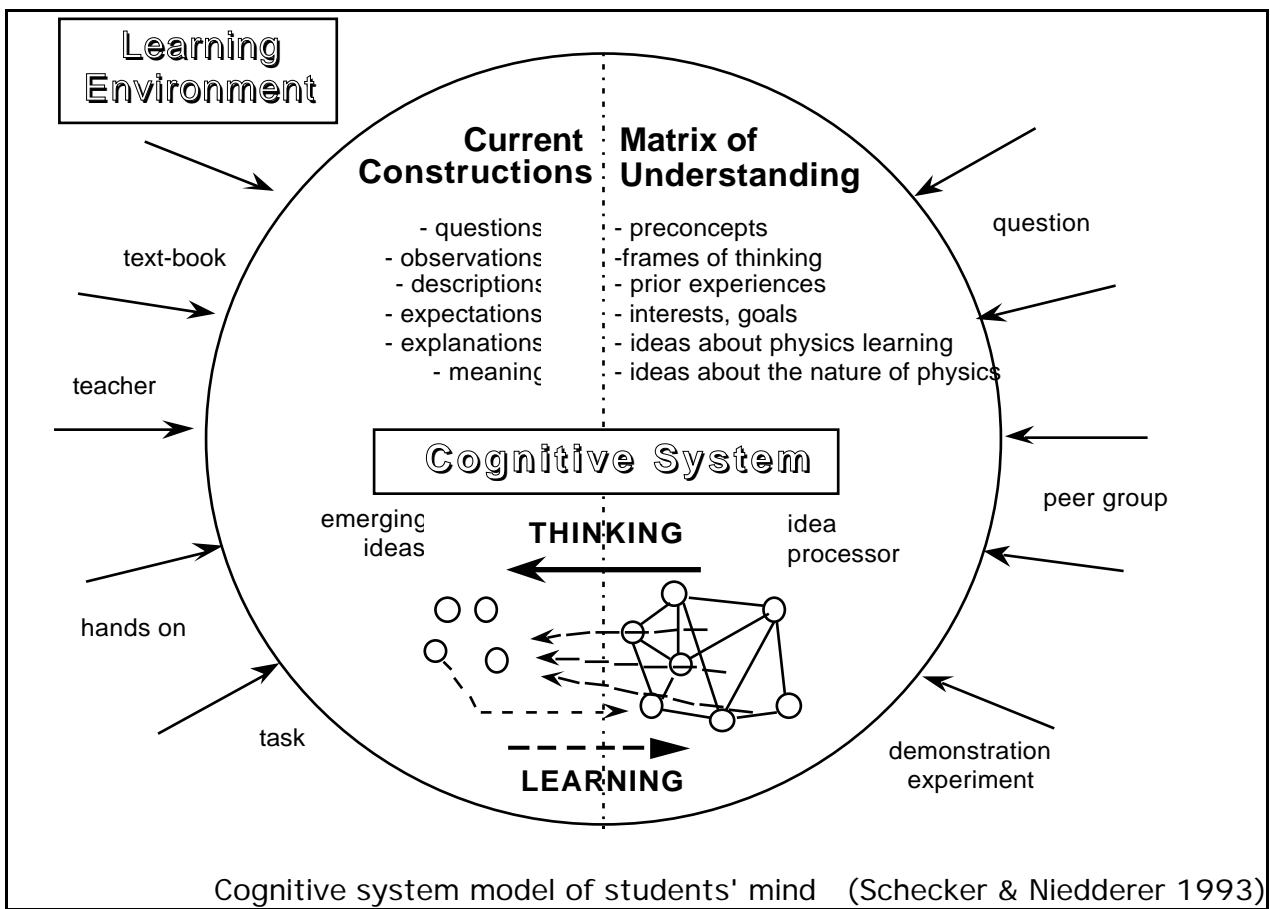
Many science educators therefore call for a new focus of physics instruction: "a deeper robust understanding" (Linn, 1988) or "teaching science for understanding" (Minstrell, 1989).

On the other hand physics is fun if you talk about the differences between the meaning of concepts and everyday life. In a careful discussion of this kind we can see advantages but sometimes also disadvantages of the physics way of thinking. For instance, physics has a very general meaning of force (Newtonian force) whereas in everyday life force always is related to a special context of a special situation. In special situations sometimes a kind of thinking like technicians have is more useful, for instance, using special formulas with special constant numbers in it is more effective in a special situation, but less generalizable. The general way of thinking in physics has advantages because of its generalizability, but the special way of thinking in everyday life (and similarly in technics) has advantages to be more precise in a special context. Perhaps we have to come to a more critical view about the advantages of physics.

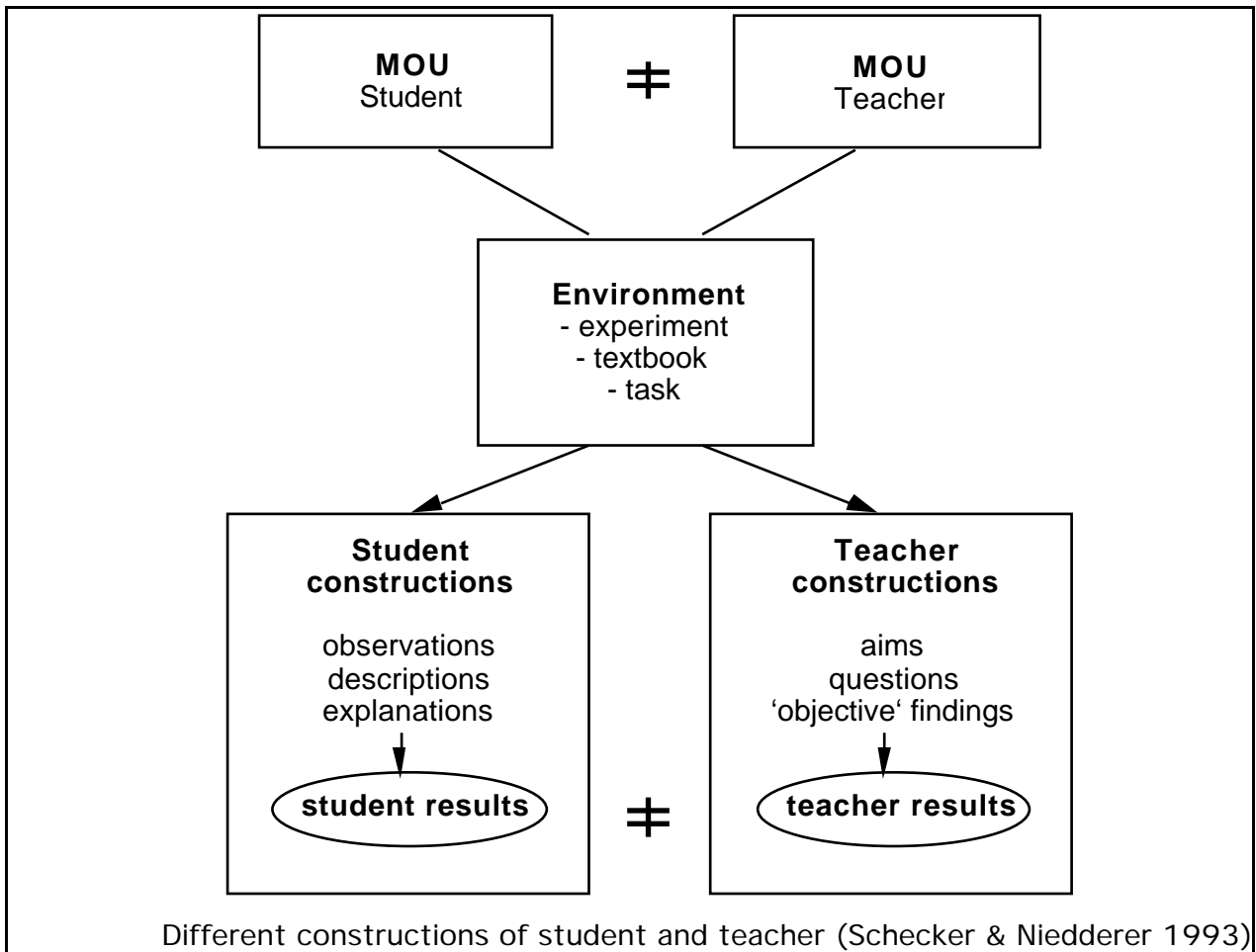
Analysis of Classroom Situation

In the following discussion I use our term for alternative frameworks, "matrix of understanding (MOU)". In this matrix of understanding we do not only see the well

known precepts of students on force or electric current, but also the students' direction of interests and more general frames of thinking, for instance what students think is the task of physics or what is their idea of problem solving in physics. For instance Schecker in his dissertation (1985) has found that students try to solve a general problem in physics by looking at one special case as one realization of this general problem (see frames above in previous sections). The frame immediately above (on the previous page) shows a graphical model of the cognitive system and the role of the MOU as stable components for the current constructions in thinking processes, whereas the aim of learning processes is to change the MOU:



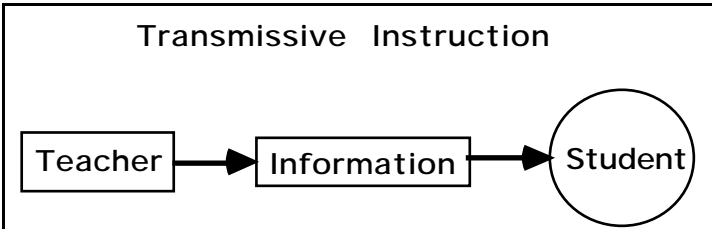
Now I come to an analysis of classroom situation:



In a classroom situation we normally have students and a teacher and both have their matrices of understanding (MOU). I suppose we agree that these matrices are different for students and teachers. Now, in the process of teaching, both the student and the teacher are looking at the same situation, for instance an experiment or a text, or what is written on the blackboard with their different views based on their individual MOUs. Also, when they talk and use the same words, for instance "current", the teacher has his meaning in his mind, the students their different meanings. The teacher, talking about "current" in his mind refers to speed and flow of charge. The student hears the word "current" and recalls his meaning more related to a substance like fuel bringing energy from the battery to the bulb.

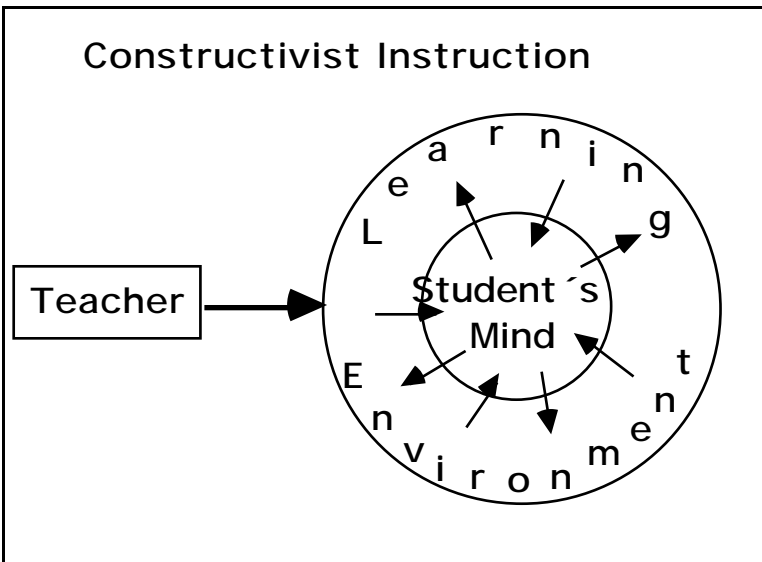
So the differences of the MOUs of teacher and students and perhaps also between different students always produces a different understanding of words or experiments being the object of communication in the class. So the result is a different construction of meanings of words, texts, and experiments. Shortly afterwards the teacher calls his

constructions the only ones, or the correct ones, or the "results". This might be the main cause of the well-known effect of physics teaching on students: "I have never understood physics". Many adults say this sentence when asked about their experience in physics education.



So the result is: We have to change instruction from what is sometimes called "transmissive instruction" to what we want to call "constructivist instruction". In the

transmissive view of instruction the teacher gives the information to the student, the only important question for the teacher is to use correct physics in his own explanations; the student then will take over like a ready receiver of truth.



In a constructivist view there is no possibility to transmit the meaning of the words together with the words in a direct process. The meaning always has to be constructed by the student using his own understanding in his own mind and thereby rebuilding his own cognitive system.

Very often teachers think that for a better understanding they simply have to use better formulations in their own explanations. This, from a constructivist view, will not be sufficient. The input of the teacher is only part of the learning environment and does not get into students' minds in a direct way. This belief of teachers also is part of the transmissive view of instruction. It is not possible - from the constructivist view of learning - to learn simply from good information. Students have to construct their own meaning, their own questions, their own actions and observations, getting input from the teacher as part of a "learning environment".

Take students' alternative view into the teaching process

This is perhaps the most important general consequence for better classroom teaching, drawn from all these theoretical and empirical results of student understanding: to take students' view into the teaching process, by elicitation of their own ideas, giving them time to work on their own ideas. Teachers should hold back their own physics view in this type of teaching process. Teaching that way is also fun for students and teachers. This is at least my own experience in teaching physics in upper secondary schools. Even the so-called "bad" students in this type of teaching can come to their own results which are important for them and which, in a special situation, make a lot of sense. These special results of students afterwards can be compared to how physics describes the same situation thereby giving a background for this comparison I talked about earlier. So, taking students' alternative views into the teaching process can be, by itself, a teaching aim before starting with the science concepts and science view.

Take students' alternative view into the teaching process

- Start with elicitation of students ideas, e.g. about prediction and explanation of experiments (Driver et.al. 1985)
- Start with an "anchor" in students' view (Clement 1987)
- Take students' ideas and "facets of knowledge" to build science concepts from there (Minstrell 1992)
- Give students a chance to develop their own questions, observations, experiments, and results from their own understanding (Niedderer 1987)

Discussion about different meanings in everyday life and science contexts

Discussion about different meanings for concepts and formulas is an important part of physics teaching in a constructivist teaching strategy. There are many approaches of teaching strategies which have this part "discussion about different meaning" in common. (Schultz et.al. 1990, Gurney 1988). For instance, Erickson & Gurney talk about "conceptual change through negotiation". In this case the teacher asks questions like "what do you mean by ..." or "what kind of experiment do you suggest to prove your expectation?" My colleagues in Bremen, Aufschnaiter, Fischer and Schwedes, suggest a teaching strategy called "play orientation" (1989) containing "students' independent actions and discussions" in which they intensively pursue their own aims of action. They try to give them a good learning environment and let them work by their own ideas and actions, not "disturbed" by the teacher. So, here also a

general advice to teachers is being more reluctant with always telling the correct physics answers.

This immensely changes the role of the teacher in the classroom: he is not in the first priority a source of information and statements about physics but more a kind of moderator helping students to organize their learning environment according to their own ideas, a kind of mediator.

One interesting difference in those teaching strategies (see also part 5) is the way of bringing in the scientific view. In some strategies this is done in small steps giving small corrections to the everyday view. In our own strategy we prefer to work out the everyday of students before we give an input of the scientific view in one big step. This kind of scientific input allows for the comparison between everyday view and science view so aiming at a general understanding of those differences. One problem is that students should not get frustrated with this comparison thinking that their own view has no value. We have made good experiences using historical comparison for this purpose.

Discussion in the physics classroom

about meaning and understanding of *different* concepts in students' view (everyday life) and in science

- Conceptual change through negotiation (Gurney 1988)
Constructivist teaching strategy: "interpretive discussion" or "negotiation". The teacher's role is a mediator between school knowledge and student understanding.
- Students' independent discussions and actions "to pursue intensively their own aims of action" thus developing new and more complex cognitive structures (Fischer, v.Aufschnaiter 1989).
- Contrasting the students' own conceptions explicitly with the scientific concepts and comparing differences as well as advantages of either perspective (Niedderer, 1987; Schecker/Niedderer 1993)
- Driver's "input of scientific view" seems to be the same idea of somehow comparing students' own view with the scientific view.
(Driver, Oldham 1985)
- Discussing "intelligibility, plausibility and fruitfulness" of different ideas
(Hewson/Hewson 1992)

5. Teaching strategies for physics instruction

There are two types of consequences of research for changing physics teaching in the classroom: changing the curriculum materials and changing teachers' behavior and teaching strategies. One general result of research is an enrichment of a "cognitive map of the field" (Clement 1992), which helps us to understand students and to plan our teaching activities and to design teaching materials. There are many groups in the world doing research and at the same time producing new curriculum materials with consequences from their research, I think especially of the groups of Hannelore Schwedes in Bremen, Lillian McDermott in Seattle, Fred Goldberg in San Diego, or Clement in Amherst, Massachusetts.

Assimilation and accommodation

I start with the teaching strategy which Nachtigall (1985) suggested some years ago. I want to focus on the main steps from my point of view starting with assimilation. This means that students try to make sense, for instance, of an experiment by using their own cognitive structure which is normally characterized by alternative views. They assimilate what they see to their own understanding.

Teaching Strategy (D. Nachtigall, 1985)

1. Arouse intense interest
2. Activate elements of personal character
3. Create awareness of problem
4. **Assimilate and explain**
5. **Arouse cognitive dissonance**
6. **Accommodate**
7. Establish cognitive harmony
8. Conceptualize
9. Make the progress conscious
10. Structure the environment

From step 4, perhaps several different assimilations may arise in a class and some cognitive conflict may be caused between those views. Cognitive conflicts could also be triggered by feedback from the teacher. From this discussion of different approaches of different students and from the teacher we should arrive at an accommodation. This, of course, is the crucial point of the whole strategy. Accommodation is also what we call "conceptual change", and it seems to be very rarely observed. Big and even

new efforts seem necessary to come to real accommodation and conceptual change in physics teaching. I in fact prefer not to think of replacing the everyday view by a scientific view but to come to some consciousness and differentiation between both views. This perhaps is a more realistic and even better aim helping students to know when the everyday view and where the science view is necessary and what the differences are. Students should learn when to use which of the two views. This would be a wonderful learning result.

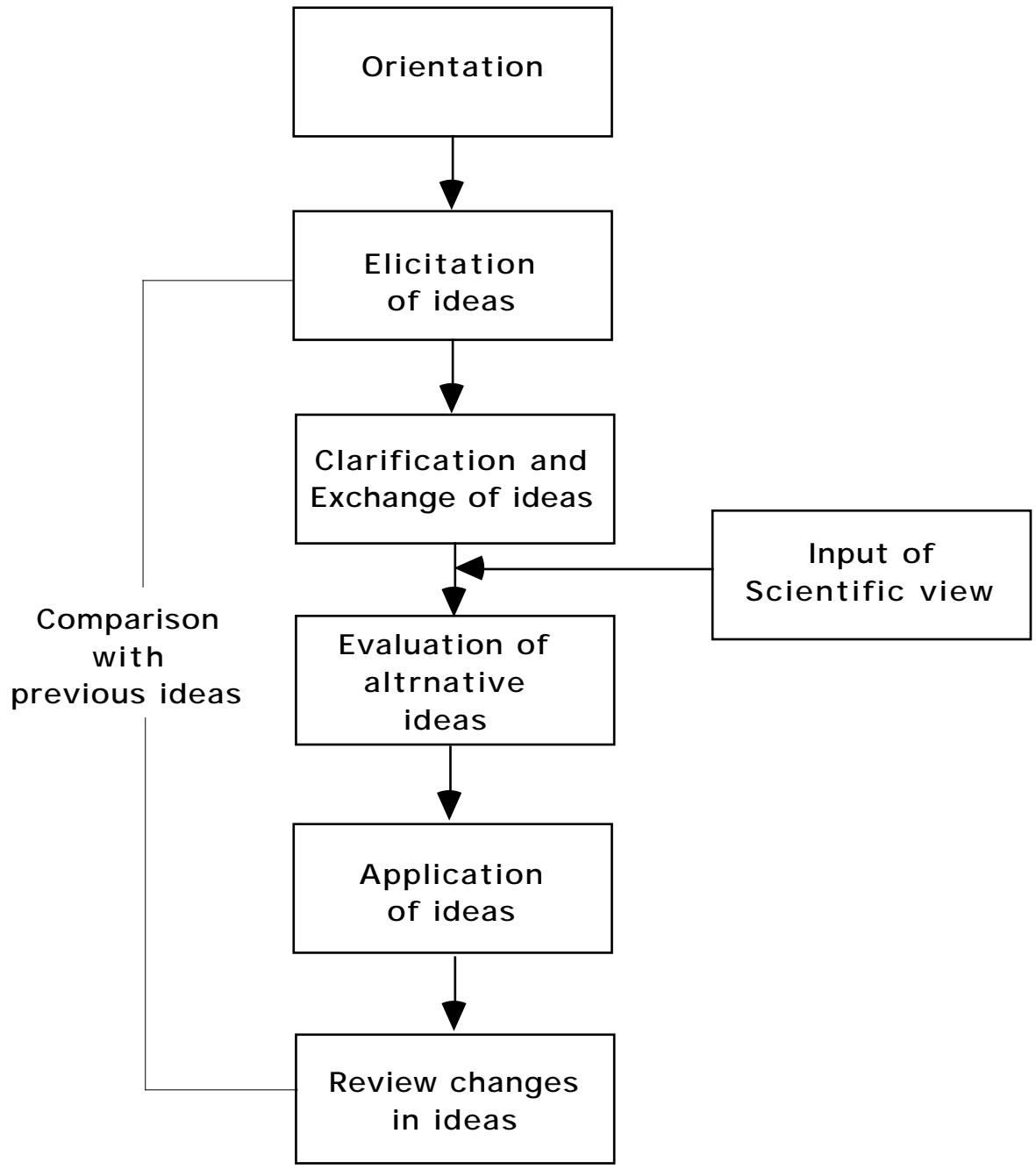
Starting with elicitation of students' ideas

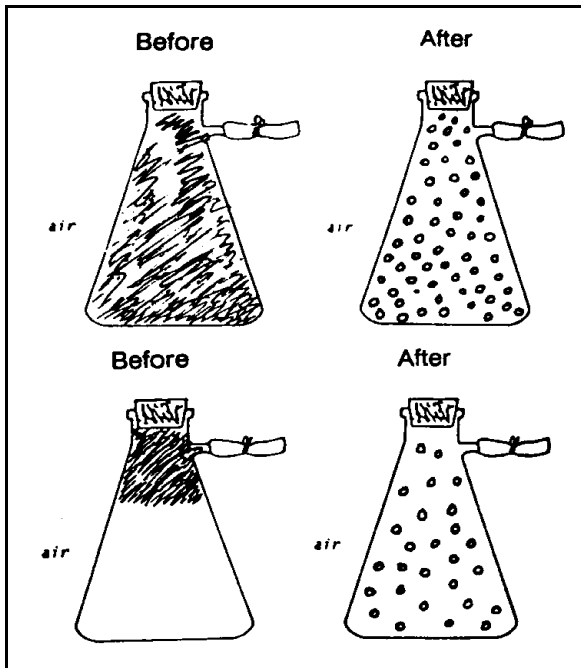
The strategy of Driver and her group (Driver, Oldham 1985) is also closely related to these ideas. They directly start with "elicitation of students' ideas". Then, after some clarification and exchange of students' ideas, there is an "input of scientific view". This is very similar to our strategy of first working on students' own view and then giving some information about the scientific view to help students to see the differences. The important aspect here is that we do not pretend to develop the scientific view from students' ideas. To us it seems more realistic and fair to tell students that there is a different view coming from science and then to work with students on the differences. We think students cannot invent the scientific view by themselves; the development of this scientific view took centuries. In later forms of their strategy the group of Driver has left out this "input of scientific view". Perhaps they have seen some difficulties with this step working primarily in lower grades, whereas we in our group work with upper grades.

I want to give a short example of this strategy from another member of the group of Ros Driver, Phil Scott. Students in explaining the behavior of gases, liquids and solids work with a conception of continuity, which is shown in the picture to the left. The pictures after teaching show that they try to explain simple experiments with evacuating a gas by now using a particle model.

The teaching strategy in this example shows the steps in more detail, for instance, showing students to draw their paintings at the walls in the classroom thus giving the chance to discuss between different groups. Also students develop their own theories, which is very close to our strategy also.

Teaching Strategy (Driver et al. 1985)





I would like to share with you out of this learning study from Phil Scott (1992) a dialog with one student at the end of the learning process:

This is a nice example of a student who apparently has some idea that there are two different views, who has both of them in his mind, and who is able to distinguish them. An example of "conscious coexistence" as a relevant type of result of a conceptual change process.

6.3 Outcomes for the Learner

At the end of the teaching, Sharron was interviewed about the relative status of her original (macroscopic, continuous) and developing particle ideas:

Teacher: *Which of these two explanations (macroscopic or particle) do you think you'd be inclined to use, you know, in everyday life?*

Sharron: *Erm, that one (macroscopic).*

Teacher: *The first one you did?*

Sharron: *Mmm. To someone who's er, sort of, don't know ... like if I were talking (laughs) to my mum or summat should I say sort of particles she wouldn't really know what...*

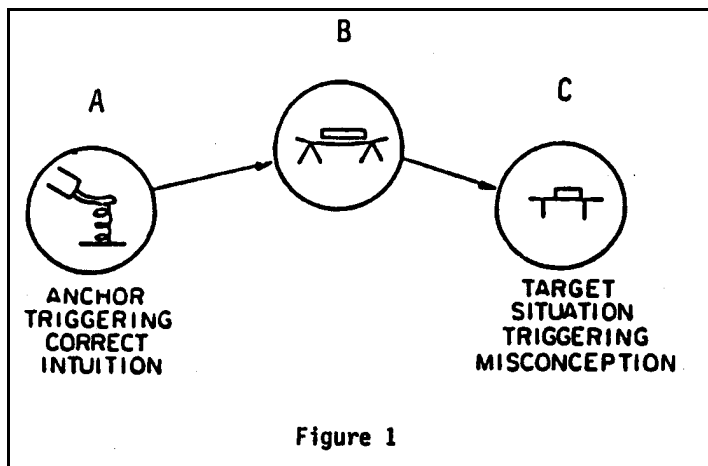
Teacher: *So are you saying that you, you wouldn't give up that kind of explanation?*

Sharron: *Well not to someone who... em, didn't know what the, it means. Like say my mum or someone.*

Sharron is thus able to differentiate between her 'life-world' and 'scientific' knowledge (Solomon 1983) in stating that the former would be more useful in talking to her mother. She has developed a new way of looking at the world but this has not been at the expense of her original, informal perspectives.

The bridging strategy

The next teaching strategy (Clement 1987) is dealing with students' alternative views in a slightly different way. It has become very well known under the name of a "bridging strategy". The example deals with Newton's 3. law for a book on a table:

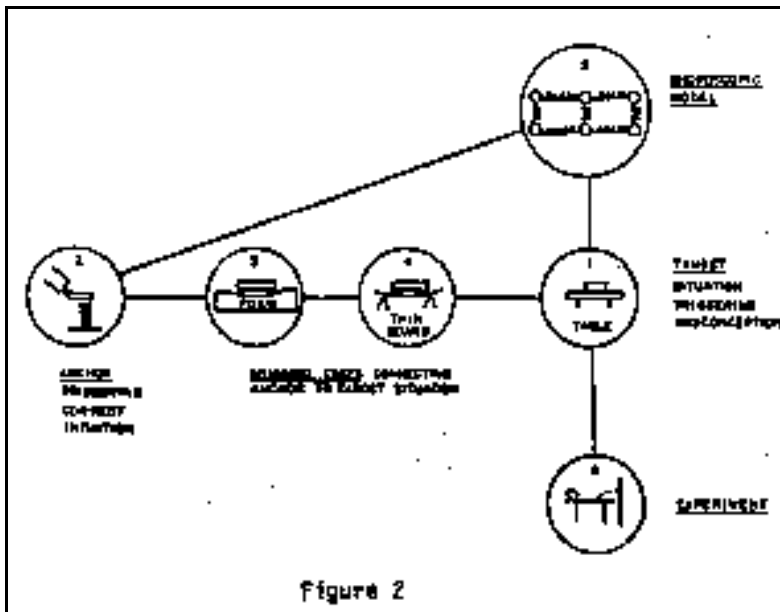


The three main elements of this strategy

- the anchor A
- bridging elements B and
- the target C

are all defined by using results of research on students' alternative frameworks.

The target is the aim of the teaching process which from research results is known to be difficult for students. In this case it is well-known that students see only one force, the gravitational force, acting on the book on a table, not the counter-force from the table on the book (Newton's third law). There is not only a force from the book on the table but also a force back from the table on the book. From research it is known that perhaps less than 10 % have an idea of this second force in this situation, whereas in the analogous anchor situation **A** of a finger pressing on a spring - analogous only from a physics point of view ! - the students do see the two forces. In this example both forces are seen by students because in student's alternative view "force" can be exerted only from active and moving bodies and both a finger **and** a spring, in students' minds, can be active and moving. So students have no problem seeing this example (anchor) with two forces. The bridging examples **B** again are analogous from a physics point of view but become more similar to the target **C**. After working on this anchor the teaching process goes on by a bridge of analogous cases. The strategy has two more important features:



The first is a microscopic model. Not only in this case but also, for instance, in electricity or atomic physics a microscopic view seems to get a high interest of students. Explanations from a microscopic model for students always seem to be more scientific than other explanations! There seems to

be a general idea of students: microscopic knowledge is the true, the real knowledge. That's the view to understand what our world is made of. The second additional feature of this strategy is to do additional experiments to explain and to demonstrate the two forces. The third feature not shown in these pictures is a kind of teaching behavior Clement and Brown used in their tutorial studies, which I think could be important for any teachers in the physics classroom. They very often asked students questions like: does that make sense to you? How does this kind of picture or this force make sense to you? They did those questions for all the examples shown in the pictures, and they were talking with students in a very open-ended way about the question how these explanations make sense to the students. Another feature is the extensive use of thought experiments. Clement and Brown, as a result of their study, stated the hypothesis that using those thought experiments can be very fruitful and successful. This is another special point of their classroom oriented research results.

The conceptual change model (CCM)

The conceptual change model of Hewson et. al. (1981, 1992) has been developed long time ago and since then has been used in several research studies. In its latest version the conceptual change model (CCM) uses a special kind of technical language around the terms "intelligible", "plausible", and "fruitful" (the so called technical language of the

CCM). Students, as a part of their learning process, are asked to talk about how the new concepts of physics are intelligible, plausible, and fruitful to them.

1. Is the conception *intelligible* to the learner? That is, does the learner know what it means? Is the learner able to find a way of representing the conception? The sentence, "the curtains eat valency,"¹ is one that we do not find intelligible, i.e., it makes no sense to us.
2. Is the conception *plausible* to the learner? That is, if a conception is intelligible to the learner, does s/he also believe that it is true? Is it consistent with and able to be reconciled with other conceptions accepted by the learner? The sentence, "the moon consists of green cheese," is one that we find intelligible, but not plausible, i.e., we understand its meaning but do not accept it as being the case.
3. Is the conception *fruitful* for the learner? That is, if a conception is intelligible to the learner, does it achieve something of value for him/her? Does it solve otherwise insoluble problems? Does it suggest new possibilities, directions, ideas? The sentence, "matter consists of small particles," is one we find intelligible. Its fruitfulness in science is enormous. When it was first proposed many scientists, however, had grave doubts about its plausibility, as do many students in our schools today.

(Hewson/Hewson 1992)

It might be that this instrument helps for discussions about meaning and about conceptual change. Perhaps it should not be over-estimated. There is something in it to talk about intelligibility, plausibility, and fruitfulness.

One study with this model (Hewson, Hennessy 1992) is also dealing with the book on the table (Newton's third law). Students, during the learning process, are asked whether the idea of this second force is intelligible to them, that means whether they can get this idea of two forces. In addition they are asked whether it is plausible to them, and also whether they think this idea is fruitful. The next figure gives an example of a student in the middle of this learning sequence:

Content

Task I: (see above)

A: I chose letter D [illustrating two equal length, opposing arrows along the vertical axis] for my answer. I think letter D is the best answer because if two forces are equal, the object they are pushing/pulling will not move. The book is not moving.

Status

Task I: (see above)

A: I chose letter D for my answer. My theory has definitely changed since I first did this activity. I think that there are equal forces...because the book isn't moving. My second theory is intelligible to me because the two forces are equal. The book is not moving so I think it is D.

A: And it does seem plausible to me because I can understand how two equal forces work on the book...And I can now see why I picked letter A before and I don't believe this reason anymore.

A: It is fruitful because I was able to apply my ideas of things at rest to figure out the answer. Even if things are not moving gravity is always working so I had to look for another force to be equal with gravity.

Contrastive Teaching for Conceptual Awareness

We assume that students must get the opportunity to work out their own ideas before they can successfully adapt new information from the teacher or the text-book (Schecker, Niedderer 1993). When students have arrived at own results, these results can be compared or confronted with corresponding notions from physics.

In the contrastive learning approach the *comparison* stage of accepted scientific theory with alternative student ideas implies chances and risks:

- A guided comparison can show students structural differences between their concept-system and the scientific theory as well as specific differences.
- A confrontation with completely different physical concepts may disappoint students and make them look upon their own efforts as useless.

Students have to feel that the ideas they worked out are appreciated even if they differ from the accepted theory. Creative own thinking has to be awarded by good scores. But appreciation of alternative conceptions as results of engaged work does not mean to give up convincing students of the superior value of scientific concepts for universal explanation and prediction. Scientific notions do have a broader scope and are more coherent than intuitive thinking. One way to get out of this dilemma is to bring in historical texts showing parallels between students' thinking and earlier stages in the development of scientific theory. The following frame gives an overview of the

two main phases which can be seen both in short and long time intervals (from about five minutes to several hours):

A contrastive teaching strategy (Schecker & Niedderer 1993)

6

Phase 1: Students develop their own ideas

The teacher: introduces a new topic by sketching a broad framework for students' activities. An open-ended problem is posed.

The teacher introduces a new topic by

- sketching a broad framework for students' activities;
e.g., "What does acceleration depend on?" ($a = f [?, ?, ?]$)
- offering a set of apparatus for free experimentation
- demonstrating an initial experiment without explaining it

The students elaborate their "current perspectives" (Linn, 1988). Students formulate concrete questions for own investigations and work on them. The teacher stays in the background as counselor on demand.

On the basis of their individual matrices of understanding the students work out questions, hypotheses, ideas, plans for experiments, results formulated in their own words.

The teacher does not interfere with students' discussions. He acts as a counselor, helps reservedly with technical problems, supervises an organized working process, i.e., keeps the students to write down questions, ideas, intermediate results, findings etc. The groups present their results in a class forum. The teacher writes them on the blackboard preserving the students' formulations.

Transition from phase 1 to phase 2:

The teacher challenges the students' views by indicating inconsistencies or suggesting additional experiments. In addition the teacher can present *historical* scientific approaches that are similar to the students' ideas.

Phase 2: Input of scientific view

The scientifically accepted explanation (concepts, principles and laws) is *offered* as an *alternative view* and compared with the students' ideas from phase 1. The teacher explains the scientific theory as an alternative view to the students' ideas — but not as 'the truth'. He shows the advantages of scientific theory for universal application and precise predictions in a controllable setting. Intuitive conceptions are described as more figurative and better suited for everyday communication about specific single events. Findings from the philosophy of science about the different structures of everyday-life thinking and scientific thinking can help to notice and accept the differences. The aim is to establish a *deeper, robust understanding* corresponding to a *philosophically sound view* (Linn, 1988). The students look back on ways and difficulties of their problem finding and solving processes. Methodological and epistemological issues are considered (reflection).

⁶This teaching strategy was first published in Niedderer & Schecker (1982).

6. Consequences for teacher education

Learning about students' alternative views

There is a rich body of research results on students' alternative views. This should be a part of every teacher education. The teachers will be able to understand their students much better if they learn to see students' alternative views. They also will be able to improve their plans for instruction or corresponding learning environments. A problem however is the lack of review articles or handbooks in this field. So it takes some effort to find useful papers for teacher education. But in every field of physics you will find some articles in journals or parts of books which contain a review of research results in the field and can be used in teacher education. Some hints are given below, more specific information can be obtained from the bibliographies of Pfund&Duit and of Carmichael et.al.

Learning about history and philosophy of science (HPS)

Another important part of teacher education is learning about the history and philosophy of science (see "course theory development" below).

Theory into practice: "teacher students" should have integrated possibilities to teach themselves in schools during their studies at universities or teacher colleges

A very important part of teacher education is the transfer process of "theory into practice". I think it is very important to have the interaction with teaching and teachers' practice in schools right from the beginning of teacher education at the universities to achieve an orientation of studies towards improvement of practical work of teachers in schools. For instance, in my university in Bremen every "teacher student" does one teaching project over a time period of one and a half years in each of his or her teaching subjects. This should be an integrated part of teacher education in universities! It is very important that students get a feeling what is and what might be important in teaching to have more motivation for learning about teaching and not only about contents of their subjects. In addition, our experience is that teacher students have a high motivation to do this kind of studies. It helps them to identify their professional aim to become teachers and not physicists.

An example of a course: "theory development in physics"

I have done this course "theory development in physics" for teacher students for many years now in Bremen. It integrates the following parts:

elaborate teacher students' own conceptions in physics; study of research results on alternative frameworks of elementary up to high school students; and the development of theories in this field in history.

The course covers three fields of physics: mechanics, especially the concept of force; electricity, especially the concept of current; and atomic physics, especially the concept of states.

Each of these three parts starts with simple experiments to be explained by the students themselves. They write small essays to explain simple experiments, for instance the movement of falling bodies or the movement of a bouncing ball (see above). Then research papers about alternative views of high school students are given to the teacher students. Then we work on a comparison between their own view and the views reported in the research papers. Finally we study some selected papers of theory development in history. For instance, with the concept force, we use papers from Aristotle, Leibniz, Descartes, Newton, and Helmholtz. Again, students work on comparisons between different views of the concept of force. It is a course for one semester with four hours a week. In the first step I probe these teacher students' own conceptions. They are perhaps already in an advanced state of studies, they had a lot of physics before that. Now they get simple questions or simple experiments to work on their own. This is done for at least two or three hours. This gives them a feeling what their own conceptions are when they come to study research results about high school students' conceptions.

Course: "Theory development in physics"

for prospective middle and high school teachers ("teacher students")

Three domains of physics:

- mechanics
- electric circuits
- quantum physics

For each domain three types of theories/conceptions are worked out:

- The teacher students' own conceptions
- Results of empirical research about high school students' conceptions
- Development of corresponding concepts and theories in the history of physics

The central idea and starting point of this course was the question: what is the difference between physics education for physics majors and for teacher students in physics? My answer to this question after many discussions is: a physics major has to be trained to use today's physics whereas a physics teacher has to be trained to see a development of physical theories in his students' minds. He has to guide students who go through different states of concepts and theories. This goal can be achieved by extensively studying research results about alternative frameworks and by studying different views of concepts and theories in history of physics, in the historical development of theories.

7. Final remarks

In spite of many good research results they seem to have little effect on the improvement of actual teaching. I think that the following suggestions could help to cope with this challenge:

- researchers themselves have to go into schools, do research there and teach themselves;
- results have to be taken to the teachers, not waiting for them to come and get them;
- teachers have to get a chance to participate in research; research projects and questions should be formulated by teachers;
- in service teacher training has to start with teachers' experiences and their (alternative !) framework of teaching;
- the aspect of "ownership" is essential for any learning process of teachers or students.

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Appendix 1:

Students' matrix of understanding in quantum physics ⁷

Elements selected from a list of 15 items found by Bethge (1988).

A) General frames of thinking

Models are no "pictures" of reality

For students, models do not represent the "true picture" of atoms. They use different models of electrons and atoms in different contexts and for different purposes - even if the models contradict each other. These contradiction is seen and accepted by students.

Models are made for visualization

Students take models as visualizations and explanations in a macroscopic scale of reality. They aim at a high amount of exactness and plausibility of a model. They would prefer to have one model as a "true picture" of the atom.

B) Specific precepts

Orbits (trajectories, states) in quantum physics

- Electrons "move" along in orbits or in oscillations.
- Students strongly express the non-existence of "trajectories" as a major postulate of quantum physics. Nevertheless they still refer to the "motion" of electrons when they think about probability distributions.
- the concept of "trajectory" is combined with notions of "probability" and "wave function" from wave mechanics in several ways:
 - the orbits are "smeared", not exactly determined, "fuzzy"
 - the probability for a special orbit is given
 - the probability of parts of the orbit is given

"Probability" in quantum mechanics

- Students use "probability" as a pure formalism to solve physics problems. It is not connected to qualitative conceptions.
- Students want to understand "concretely" how the probability distribution originates. They ask for a causal explanation with "movement" or a "mechanical" process.
- Students connect the meanings of "inaccuracy" and "events by chance" to their conception of probability.

The concept of energy in quantum physics

- The quantization of energy is readily accepted by students. They soon start to use it as a basis for their own reasoning. They do not ask for a physical explanation of this fact. Students seem to have no "need" for a more sophisticated atomic model. To the contrary: A more simple "model" can be based on this assumption.)
- Students use the concept of energy actively in their own reasoning. The conservation of energy plays an especially important role in students' own explanations, e.g. related to emission and absorption of light in atoms or molecules.

⁷ Different (sometimes contradictory) elements might be shown by different students

Appendix 2:

Students' matrix of understanding in science philosophy ⁸

Elements selected from a list of 40 items found by Meyling (1990)

A) Understanding of central concepts of science philosophy.

Laws of science are

- descriptions of basic natural facts, such as the rotation of the earth
- true pictures of laws of nature
- hypothetical propositions of science, gained by inductive or deductive methods, they may change in time

Hypothesis and theory

- Hypothesis and theory are synonyms, theory is preferred.
- A theory is far away from reality, of little practical value
- Theories are used for explanations, not for predictions

Models are

- representations of a scientific subject matter for the purpose of explanation and visualization
- made to represent certain aspects of reality
- taken for reality. The limitations are not clear

B) Understanding of the scientific process

Rationality of scientific processes

- Speculation and intuition have a negative meaning: they are of little value for science.
- Starting the process with hypotheses and then working with deduction is rated low.
- The scientific process should be theory-guided with experimental testing afterwards.
- The influence of general philosophy on the scientific enterprise is rated low

The meaning of experiments

- Students like to make their own experiments, but they want theory and experiment to be balanced in physics instruction.
- Experimental results have one unique interpretation.
- Experimental results can be interpreted in different ways: therefore scientists should hold back their personal view
- A statement of physics is true once it is successfully tested by an experiment

The pathway of scientific discovery

- The pathway is linear
- It begins with a basic law of science or an experiment or a hypothesis or an observation
- The end point of science is a basic law of science or a theory

⁸ Alternative conceptions refer to different groups of students or different states of the learning process.