Epistemological Beliefs of Students in High School Physics

Hans Niedderer, Thomas Bethge, Heinz Meyling, Horst Schecker
Institute for Physics Education, University of Bremen, Germany

Abstract

Two empirical investigations on students' matrices of understanding in mechanics and quantum physics had an additional focus on general frames of thinking related to science philosophy. A third study was directly focused on epistemological beliefs of students. All three studies were done with a qualitative approach using mainly an interpretive analysis of classroom protocols with additional data from questionnaires and interviews. Results give support to the general hypothesis, that there is a fundamental structural difference between everyday life thinking and science thinking which should be addressed in physics teaching. Other results show students' understanding of basic concepts in science philosophy, e.g. law, hypothesis and model, and their understanding of the scientific process envolving the interplay between theory and experiment.

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Address:
Hans Niedderer
Institute for Physics Education
University of Bremen
D 2800 Bremen
Germany

FAX: (49)-421-218-3601
Tel.: (49)-421-218-2484/2965
e-mail: HANSN@THEO.PHYSIK.UNI-BREMEN.DE

1. Alternative Frameworks and the Teaching of Physics

Investigations about students' alternative frameworks have become a main issue in physics education research all over the world. This has been demonstrated by several international conferences and seminars during the past years .

To our opinion the main hypothesis in this field of research is:

- Learning has to be seen as a process of self-development of the learner, starting with the learner's present view, his alternative frameworks. There is no direct transfer of meaning (e.g. of concepts like ´heat´ or ´force´) from teacher to learner! In order to bring an individual learner to such a self development process it is most important to know and take into account his motivational forces coming from his general frames and interests. This view of learning is part of the all embracing paradigm of a constructivistic view of learning.

Our concept "Matrix of Understanding (MOU)" is a special concept of alternative frameworks. This concept has been developed in my research group, starting from a point of view of the "New Philosophy of Science" (Kuhn, Lakatos, Holzkamp and others, c.f. Brown 1977). It claims that every process of knowing in physics in an individual person is determined by beliefs and preknowledge systems which govern the actual thinking of this person (researcher, teacher, or student). While Kuhn speaks of "paradigms" or "disciplinary matrices" and Lakatos of "research programs" - concepts aiming at the scientific community - we call the respective ensemble of cognitive guidelines referring to an individual person in an act of discovery the (individual) **"matrix of understanding (MOU)"**. The MOU is the corpus of all dispositions that influence the way a person deals with a special situation, a phenomenon, or a problem. Those dispositions influence especially the observations, first ideas, descriptions, and tentative explanations. On the basis of this matrix of understanding (MOU), the individual person

- constructs his/her own meaning for a concrete special situation, coming to observations, explanations, questions, etc.
- starts - in the case of learning - a process of conceptual change. This means a constructivist procedure which ends up in some kind of new structure of the matrix of understanding (MOU).

The concept "matrix of understanding" is related to other concepts like alternative frameworks, conceptual understanding, cognitive structures, conceptions and perceptions, etc. In our opinion it is important

- that the concept ´MOU´ is applicable to every individual (including teachers), not only to students. This helps to see the teaching process as a complex process of understanding where teacher and student construct meaning for what they are seeing and hearing "from the other side" (from outside themselves) on the basis of their own MOU,

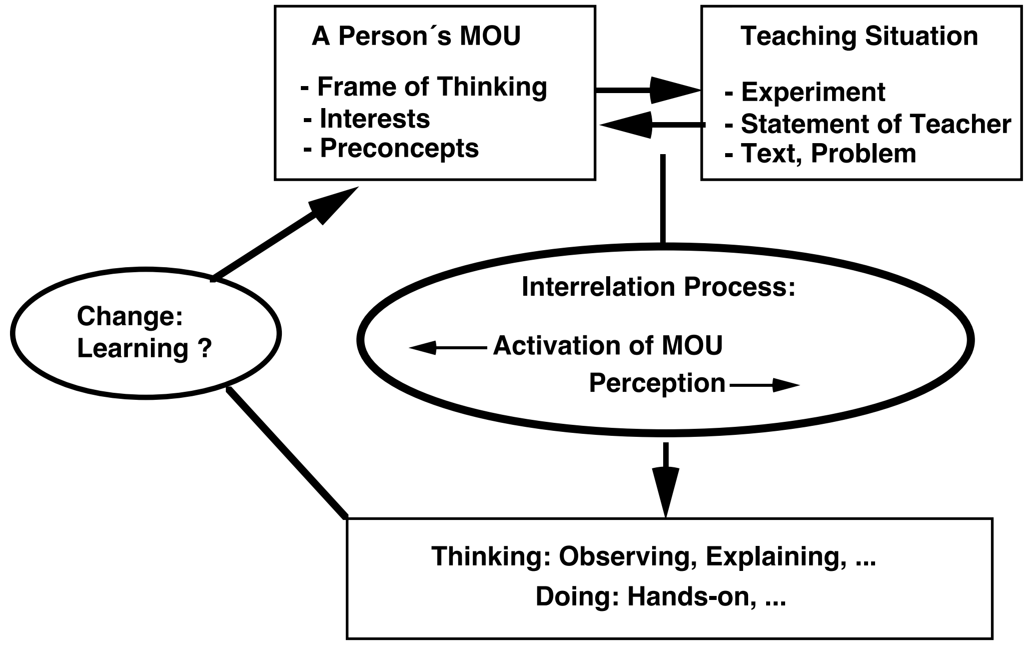

Fig. 1. Matrix of understanding (MOU) in a teaching situation

- that the MOU is not a matter of right or wrong ("misconceptions"). Different persons can hold different alternative viewpoints having their positive meaning in a special class of situation contexts,

- that the MOU comprises not only cognitive structures but also the affective domain. In physics teaching this especially means that there are preferred directions for students' questions depending on the special area of content,

- that the MOU contains special elements of conceptual understanding (e.g. preconceptions about force, energy, electric current) and more general frames of thinking (e.g. concerning task of physics, the relation between theory and experiment).

So we see the following **components of the MOU** as the most important ones:

- general frames of thinking
- affective components (interests, preferred directions of questions)
- preconceptions of concepts in physics (and other components of conceptual understanding)

We work on the basis of the general hypothesis, that there are many differences between the MOU of a teacher (MOU-T) and the MOU of students (MOU-S), differences in structure and in content-specific details (see 2. below). If this is the case, we can give a general analysis of physics teaching:

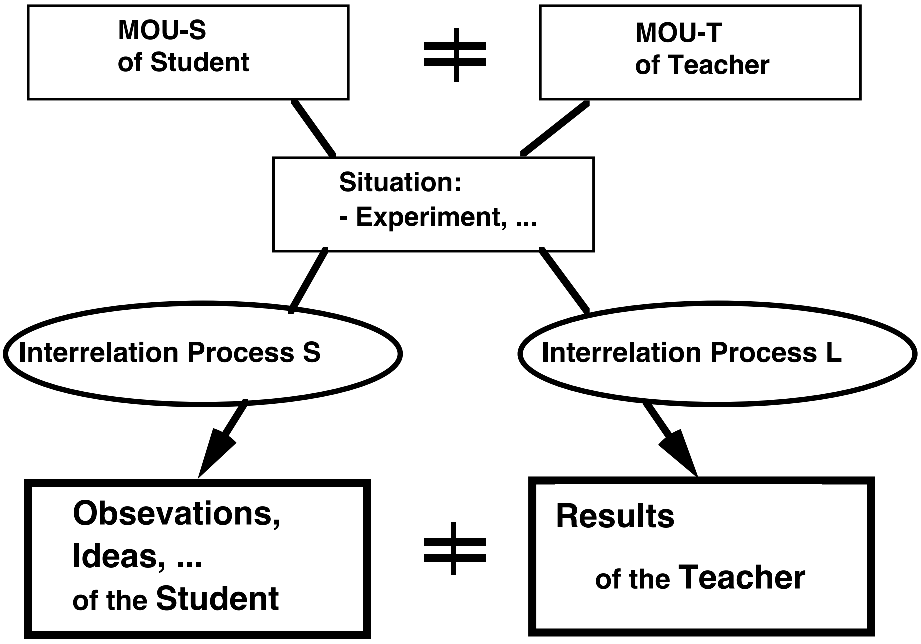

Fig. 2. MOU of student and teacher in a classroom situation

This situation which is generally unsatisfactory for students, is perhaps the origin of the following well known reactions of students on physics teaching:

- "I have never understood physics !"
- Rebellion against physics teaching, either with arguments (seldom) or by disturbing lessons (quite often)
- The "bright student" has learned to ask the "right" questions and to use the language of physics.

Our main consequence for physics teaching is: We need phases in the teaching process where the teacher holds back his view of understanding (his MOU) and follows the ideas and questions of students, and where the teacher tries to understand the students, perhaps by the help of knowledge of research results in the field of students' conceptions (Niedderer 1987).

2. Epistemological beliefs of students in high school physics

2.1 Science and everyday life: cognition in different domains

Our physics education research group has for many years been focusing on evaluating the new philosophy of science (Popper, Kuhn, Lakatos and others) on consequences for teaching. Research resulted in three doctoral dissertations on students "matrix of understanding (MOU)" in the fields of mechanics, quantum physics, and epistemological beliefs in high school physics (Schecker 1985, Bethge 1988, Meyling 1990). One research question in all three investigations was: What are the more general frames of thinking and the epistemological beliefs of students, which are important for physics learning? How do their epistemological beliefs compare to the views of the new philosophy of science?

All three investigations employed qualitative interpretive research. In all of them data were taken primarily from classroom dialogues with additional data from questionaires and interviews. In interpretation, high priority was given to those statements of students, which were spotaneous, not direct responses to the teacher's explanations or questions. The process of interpretation is seen as an iterative procedure. First hyptheses about elements of students' matrix of understanding are generated on the basis of present research studies and theoretical assumptions about what should be the result of prior instruction. The procedure then goes on by looking at the data with theses first hypotheses. This leads to changes in the hypotheses, or construction of new ones, and a first set of pieces of evidence and counter evidence in the data. Research then re-enters the interpretation of empirical materials. Results finally are reported formulating the final hypotheses and selected pieces of data giving evidence and/or counter evidence.

Out of these theoretical and empirical results the idea of a general structural difference between concepts used in everyday life thinking and in scientific thinking was developed (Schecker 1985, Niedderer 1987), especially by studying a paper of the German philosopher G.Böhme (1981) on the relation between science and (everyday life) experience. Recently Reif and Larkin (1991) have published similar ideas about differences of cognition in scientific and everyday domains. We will try to compare both views and then give empirical results about related features of the students´ cognitive system.

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.

The main goal in the everyday life domain is "to cope satisfactorily with one´s environment, leading a good life" (R)[1] 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 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) [2]:

> "*The 'indexicality' of prescientific 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.*"

and

> "*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. So '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 or 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 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.

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

[2] Translation from German: HN

	Scientific domain	**Everyday domain**	**Related features of the students‘ cognitive system**[3]
Domain goals	Construct a theory to explain and predict many single events by a small set of **general rules**	Solve problems in specific **single situations**	Goal of physics: „to investigate special situations with sophisticated methods“
Knowledge structure	Concepts are defined sharp and general; being embedded in a theoretical scheme they have a **context-free meaning**.	Concepts are **vague in general** but have sharp and clear meanings in practical situations which depends on the context (indexicality)	Central elements like heat or force are represented as "cluster concepts" which merge different aspects of related physical concepts in a universal explanatory scheme
Language, mathe-matics	Mathematical language is used to express the generality of relations between **quantities** for many single data.	Mathematical language is used to compute **numbers** for specific questions in a given situation	Formulas are looked upon and used as **computation rules**, their conceptual content is not reflected.
Relation to experience and reality	Experiments and observations are theory-laden abstractions; experiments serve as "realizations" (Holzkamp) of a theory in the touch-and-show reality	Holistic approach to specific situations, taking into account all available informations with respect to the purpose of an intended action	Attempt to solve new problems by applying old solutions from well known episodes instead of infering from general concepts and using general rules

Tab. 1. Schematic comparison of everyday and scientific knowledge domain, and related features of students´ cognitive systems

Whereas in science we want to arrive at all embracing theories to cover many different kinds of situations and problems (consistency) and therefore use few concepts which are defined very sharp for the general case, in everyday life we are more interested in solving single problems in specific single situations, using a great variety of context specific ideas with broad concepts, vague in general but with a context specific meaning in the special situation they refer to.

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[3] From results of Schecker (1985), see 2.2 below.

Correspondingly, we see the role of mathematics: In everyday life we use mathematical language to give or compute numbers in specific situations, whereas in science we use mathematical language to express the generality of relations between quantities for many single data. The relation of both domains to reality and experiment also is different: In everyday life every single situation or experiment is analyzed holisticly, interesting by itself in all aspects given by the special situation. In science every experiment is seen as an application of a special theory in mind and all other aspects of the situation are not relevant.

So the main goals and related conceptual tools are quite different. Students tend to integrate scientific concepts that are introduced in physics instruction into a frame of thinking more related to goals in the everyday domain. This means that they easily vary the meaning of their broad concepts in different situations, adapt them to specific purposes of explanations, and tend to use many different ideas in different situations instead of trialing the universal applicability of few strictly defined scientific concepts. Students have no confidence in the power of so few concepts being able to cope with all the complex reality. Instead of looking for parsimonity (being able to make predictions and explanations for a maximum of situations with a minimum of concepts and relations) students believe in the power of many ideas, one for every new problem. So the notion of consistency is related to the idea of the goals and the best way to cope with new problems.

Our empirical studies relate to this discussion in two ways:

- the students´ matrix of understanding contains cognitive elements about the goal of physics, which show a mixture of everyday life goals (e.g. to cope with everyday life situations) and of physics goals as students see them (e.g. to use sophisticated methods).
- Analyzing students preconcepts, e.g. on force, we found exactly the type of concepts that were described by Böhme as ‘indexical’. We call them "cluster concepts": concepts with a vague general meaning but with a cluster of different special meanings for special situations.

2.2 Students‘ cognitive system in the transition state between scientific and everyday life thinking

This chapter expands on the points in the third column of Table 1 which lays out the comparision between everyday and scientific knowledge. The four items are described in more detail and illustrated by empirical data from investigation that Schecker (1985) carried out in high school physics classes. The material is derived from audiotapes and questionnaires in high school physics classes after a period of at least 2 months of a mechanics course. The students were 15 to 16 years old.

2.2.1 The goal of physics

A wide-spread picture among students about physics as a scientific discipline goes like this:

> Physics deals with things that surround us in the everyday world. Physicists rebuild this world in the laboratory and investigate specific phenomena with sophisticated experments.

This general framework is not only a hypothesis about what physicists do; it also expresses what many students expect from physics and physics instruction: They want to learn, how particular things work. They would like to have concrete explanations for given phenomena. Science instruction in the lower classes supports this view of physics. The content of high school physics courses then shifts the focus from vividness and clearness to theoretical abstraction and generalization. Many students are disappointed, as shown in the following statements:

> *I think science as a whole is not very useful for understanding real processes. It deals always with nothing but laboratory experiments, frictionless moving without air resistance, mass points and all that. Where you will find such things in real life? It would not even be possible to exactly calculate the course of a ball rolling over cobbles. Real world things are much too complicated to describe them with physical laws. And, apart from that, you can manage everyday life well without knowing them.*
>
> *I think science is not so bad in its fundamental principles but, in my opinion, in science-teaching theoretical matters are prevailing too much. Also, too little is learned about matters encountered in real world. But I hope this will change now in higher-grade teaching.*

Only 19% of 449 students in high school physics courses agreed to this questionnaire statement:

> „Physical science aims at establishing general laws. It shows little interest in making statements on particular matters.“

62% disagreed. On the other hand the statement ...

> It is the scientist's profession to examine processes we encounter in everyday life in a more systematical, precise and determined way than the "ordinary people" can do.

... found unanimous approval (91%).

This picture of physics is partly due to a lack of differentiation between physics and engineering or technics:

> *Many people have cars and don't want to take it to the workshop eachtime something is wrong with it. Therefore it is necessary to have a notion of how the engine functions. You will get that notion only by studying physics.*

2.2.2 Cluster concepts

Central elements of the students cognitive system are represented as "cluster concepts" with low degrees of reflection and expliciteness. Viennot (1979) uses a similar category, called „undifferentiated explanatory complex“. Students use the word „force“ for a great variety of physically different concepts: Newtonian force, momentum, potential and kinetic energy, torque, time integral of force etc. It is not simply that students use the same word to denominate different concepts that they implicitely distenguish. For them „force of motion“, „force of impact“, „acceleraing force“ etc. are different modes of one universal explanatory scheme. They are considered to be essentially the same. „Force of motion“ can be changed into „force of impact“ during a collision. The „force of the mover“ passes over to a moving object as „force of motion“. Newtonian force, introduced in the physics course, is added just as another facet to the cluster.

Still students learn to make certain distinctions between the „forces“, for instance to associate the correct formulas needed to solve standard textbook items. But this distinction ist not a general one between a relational intensity concept force and energy as a extensity concept to balance a process. „Force“, „energy“, and „momentum“ are all three seen as interchangeable substances or properties of bodies. What characterizes force/energy/... is mainly the ability to cause an effect.

A very nice illustration of the category *cluster concept* is given in a student‘s answer to the question, whether he found it necessary to discriminate between the three terms. He put it this way: „Well, of course it‘s necessary. After all they are all different forces.“

The following student statements are answers to the questionnaire item:

> „Describe in a few sentences, what you understand by force, energy and work! (Where are differences and common aspects?)“

The questionnare was distributed to 70 students in high school physics classes directly after the mechanics semester (4 months).

> *„Force is a special form of energy.“ (several answers)*
>
> *„Force can have the form of energy or some other form.“*
>
> *„Energy is the cause of all occuring forces.“ (several answers)*
>
> *„Energy is force which is conserved.“*
>
> *„Energy can be stored, force cannot.“*
>
> *„In order to exert force, one needs energy.“*
>
> *„I would say that force and energy are principally the same. The only difference, I think, is that a body can have energy from the beginning while force has to be continually exerted.“*
>
> *„Force and energy have in common that they can cause an effect on a body. We speak of force, as far as I know, only when a special sort of ‘effect‘ is achieved, of the form that moves the body in the widest sense. ‘Energy‘, for instance heat energy, can change the properties of a body, can make chemical reactions possible etc. The ‘energy‘ of a body is given by the motion of its particles. So it can mean more than ‘force‘, which I would like to restrict to mechanical effects.“*
>
> *Several written answers show how students really try to find differences when they are required to. But they do not feel the need to make explicit and clear disctinctions between energy, force and momentum in their verbal statements in classe just for the abstract cause of systematization and intersubjectivity. They find it sufficient when in a given communication situation it is implicitely clear which facet of the general explanatory scheme force is meant.*

2.2.3 Orientation towards formulas

Students regard ‘formulas‘ as the central products of physical investigations. They do not differentiate between definitions (e.g. a=ds/dt) laws (e.g. a=F/m) and special solutions of differential equations (e.g. a=v*t). They supose that any problem can be solved with simply the right equation at hand. Verbalisations of their conceptual content and qualitative assesments of problem situations are taken as decorating accessories that can soon be forgotten. Formulas serve as computation rules to generate numbers.

Students believe that physical competence is expressed in the knowledge of many ‘formulas‘. Formulas are „exact“ and seem to provide orientation and „security“ in physical contexts. Standard examiniation tasks, which have often more to do with the mathematical rule of three than with physical reflection, strengthen this view, when students mainly have to memorize formulas.

Our first example shows how teachers foster formula orientation. The class is talking about the relationship of force and change of momentum.

Frank: I do not know how to start.

Teacher: Well - what is impetus?

Frank: What impetus is? Well - what shall I say? There are many things one could say.

Teacher: You can say that quite clearly!

Frank: Well - m times v, or mass times velocity.

Teacher: Exactly, that is all we need to say, isn‘t it?

But teachers who try to put more weight on qualitative contribuations are also confronted with their students‘ formula oriention. The following dialogue is took place in a lesson before a written test on kinematics:

Peter: (asks the teacher) What will the test be about?

Teacher: What would you expect it to be about?

Kurt: All we have learned is ‘s divided by t‘. That‘s how we can calculate velocity.

Martin: And then the acceleration by ‘v divided by t‘

It has to be mentioned here that the unit on kinematics had taken 15 lessons with many experiments and qualitative discussions about appropriate descriptions and the definitions for the physical quantities involved.

We meet a simular situation in a second course. The students asked whether they would be allowed to use a formula sheet in the exam. After the teacher had agreed - he did not consider the memorization of formulas as so important for the test - the next question was:

Sven: Will all the tasks include calculations?

Teacher: No, not all of them.

Kai: Again one of those prattling jobs!?

Teacher: There are phenomena the projectile motion for instance and inelastic collision where we simply cannot calculate everything.

Tom: (in a pejorative voice) I see, again one of those tasks where we have to write stories.

It takes time and effort to change formula orientation which is a deep-rooted element of the students‘ matrix of understandig. A chance lies in intensifying qualitative elements in physics instruction and in examinations.

2.2.4 Thinking in realizations

Many students tend to transform problems that are meant as thought experiments into conceived realization. Their question is: What would happen if the experiment was actually carried out?“ In this process of transformation many specific features of an imagined situation, that were abstracted from in the original task, are re-introduced into the problem.

This tendency is often intensified by an implicite or even explicite resistance of students against „non-realistic“ assumptions, particularly against the exclusion of friction, as it is proposed in many mechanical investigations. The following passages from a group interview illustrate this point.

Oswald: Physics always starts from ideal assumptions. I have always been angry about that: You speak of a vacuum - I cannot imagine that term. Such things can never be realised. Exclusion of air friction - such can hardly be imagined. It is not allowed to exclude such things in nature. It is not allowed in nature to say a car is running always at the same speed when gas is taken away. There are always so many other things involved. But you can hardly transfer these as the many formulas we learn are based on ideal conditions - somewhat in a vacuum. There is no friction, no further disturbing influences. Is difficult to transfer therefore.

Rainer: Above all it is hardly known where to use it - in real situations. It is known, that's true, things would happen in one way or another in case there existed a vacuum but this cannot be transferred to here and now.

Falk: I think it would be better to exclude disturbing factors for the beginning and then, in a second step - such as space engineers perhaps do calculating the start of a missile - based on the experiences made with a vacuum they then include the air, thus continuing on what has already been elaborated and adding the further factors.

Kai: I think it would be hardly possible to deal in physics without recurring to any simplifications, particularly in physics teaching at school, if one tried to approach the object directly. This would then be much more complicated. It is then better - if you then have such a model which perhaps helps explaining and simplifying.

Oswald: Well, then someone says "imagine there was no friction", and then the car ... I think this is hardly to be realised, and then it is also more difficult to calculate such propositions.

Falk and Kai seem to have some understanding of the scientific methodology, which assumes that the true order of things is only accessible by idealisation, i.e. by the mental construction of pure phenomena which cannot be found in the 'touch-and-show-realtiy'. Many other students, like Oswald and Kai, think that physical laws refer to ideal laboratory-worlds and have little significance for everyday experiences.

They doubt whether it makes sense to analyse or reflect upon frictionless motion, because they cannot see any connection to their own experiences, where motion is always exposed to friction. They prefer phenomena that seem to be directly accessible for the "naked eye".

We asked 254 high-school students to comment on this statement (Schecker 1985, 455):

> „In physics lessons there are often assumptions or experiments of thought, which can obviously not be realised in actual experiments, like completely excluding air resistance and other frictional effects or assuming an infinitely lasting linear motion.
>
> Do you think this method is useful or not useful? Give reasons for your answer."

The answers were categorised (with quotations from students' papers):

1) Refuses to deal with ideal cases. For instance:

   „Why should I consider something, that does not exist?“

2) Acquiesces in ideal cases, because

   „They make it easier.“

3) Considers ideal cases an independent reality (compare MOU-element iii):

   „I don't need to refer everything to reality. I am simply interested in physics.“

4) Looks upon ideal cases as tools for structuring the 'touch-and-show reality':

   „They work out the basic principles of a process.“

Only 1 out of 10 students openly called the method senseless (category 1). But if one looks closely at the 83% affirmative answers (categories 2 to 4), one finds that only about a third of the reasons given show a true apprehension of its function (category 4).

2.3 Student‘s ideas about the scientific process

The following pages shortly list some of the empirical results from Bethge (1988) and especially Meyling (1990).

2.3.1 Reality and models

First we look at students´ notions and interests about models and reality. Students are very interested in "reality". (This reality has to be discovered by science.) As in everyday life students seem to be most interested to gain more knowledge about reality itself:

> *Student: One is striving by all means to know what reality is...Physics is not only done to calculate things but rather to find out what it´s all really about.* (Meyling 1990, 121)

In a questionaire five ficticious statements of students were given. Vera´s statement got the highest rank of rating agreement, Bernd´s statement the lowest. Lars´ statement would be nearest to the main goal of physics as discussed above (predictions, parsimonity). This again shows students view of the main goal of physics: to understand the reality of everyday life.

Vera:
I wish to understand how things are connected in reality. 4,3
Bernd:
What a nonsense! That's much too complicated for us.
You will learn that only in higher-grade studies. 1.8
Gesa:
You wouldn't even learn it here. Nobody knows how things
are interrelated "in reality". Also at college you will only be
confronted with theories and models, on a higher level
than at school,of course. 2.8
Lars:
I'm not at all interested to know how things are in reality. I am
content if my calculations coincide with my experiments and my
suppositions on the result of an experiment will be confirmed. 2,3
Vera:
This would not be satisfactory for me. Supposed you have two
different theories on the same phenomenon it is impossible that
both are true! 3,3

(N= 108, students of grades 11 and 12, 5 = fully agree, 1 = totally disagree)

Different groups of students have very disparate beliefs about models. On the one hand students seem to have learnt that models are not reality. On the other hand the limitations are sometimes not clear. In the students´ view models are

- representations of scientific subject matter for the purpose of explanation and visualization; students e.g. take models of atoms as visualizations and explanations in a macroscopic scale of reality. They aim at a high amount of exactness and plausibility of a model.
- made to represent certain aspects of reality; models are not "pictures" of reality, they do not represent the "true picture" of atoms. Students use different models of electrons and atoms in different contexts and for different purposes - even if the models contradict each other. This contradiction is seen and accepted by students (Bethge 1988,p.97).
- sometimes taken for reality; the limitations are not clear.

2.3.2 Students' understanding of the scientific process

> *Tom: We only need to falsify once but we can verify as often as we like and still it is not clear whether the facts are right. It is easier to falsify.*
>
> *Teacher: That's right. Falsification shows our hypothesis is wrong. Verification proves - nothing. In our experiment the ratio of oscillation might be 1:2 although the influence of the centrifugal force is irrelevant.*
>
> *Spontaneously Marion's sigh: Always this relativity: there is no certainty!* (Meyling 1990, 273)

Students tend to have a high opinion of the rationality of the scientific processes. As a consequence, speculation and intuition have a negative meaning; they are viewed to be of little value for science. In a similar way starting 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 process is rated low. (Meyling 1990, 74)

Experiments are also viewed as objective, experimental results have one unique interpretation, at least scientists should hold back their personal view. A statement of physics is true once it is successfully tested by an experiment

Students tend to see a big difference between physics research and school physics:

> *Student: We have to distinguish between experiments in school and those carried out in a physics research laboratory. In school one knows that the law is true and the result is known before. If the experimental results do not fit they are manipulated. If physicists do an experiment, they expect certain results, but they are not allowed to manipulate the experiment.* (Meyling 1990, 92)

Also, the pathway of scientific discovery is expected to be linear. It begins with an observation, a basic law of science, an experiment or a hypothesis. The end point of this pathway is seen in a new basic law of science or a new theory.

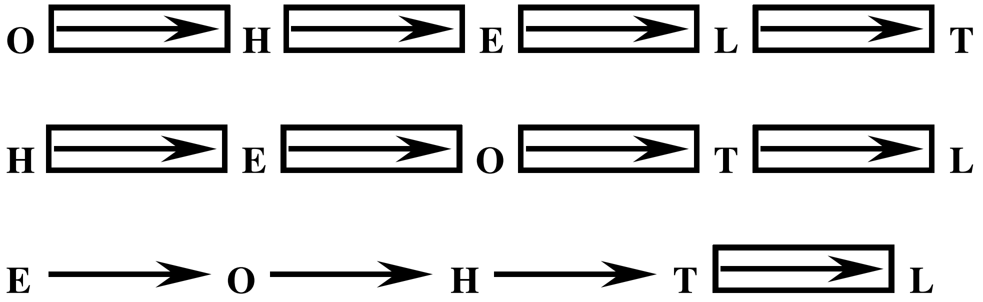

Fig. 3. Some of students´ ideas of the pathway of a scientific discovery.
O: observation, H: hypothesis, E: experiment, L: law of nature, T: theory[4]

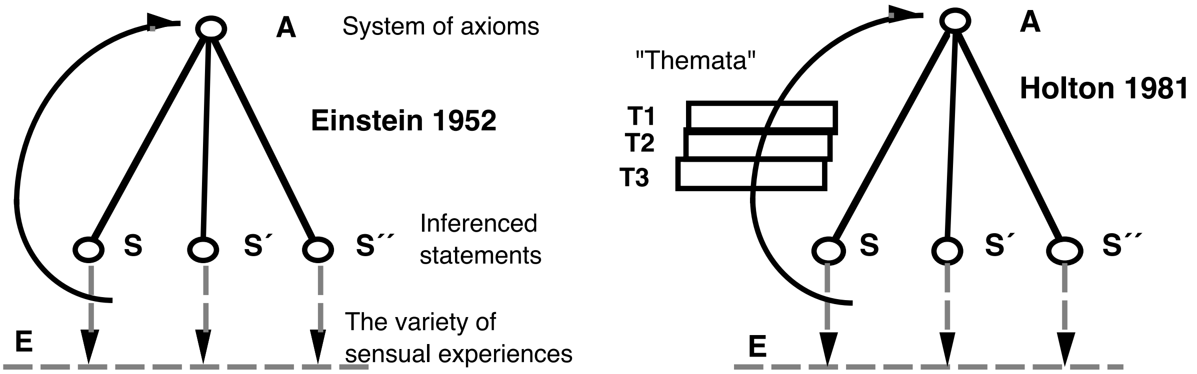

Fig. 4. Two types of the pathway of a scientific discovery in science philosophy.[4]

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[4] Meyling 1990, 103-117

Scientists reflecting their own work see much more complexity in the relations between theory and experience, as shown in Fig. 4 by sketches of Einstein and Holton.

3. Consequences for teaching

We see consequences of these results in three directions. First, to elicitate, elaborate and clarify students´ own views and to compare it to a physics view for a special subject might be an important step towards understanding physics. Second, using examples and texts from the history of physics can demonstrate some of the intellectual demands and uncertainties in the creation and discovery process of a topic which often have some parallels to students´ own difficulties. A teaching strategy combining these two aspects has been described with examples in Niedderer (1987, 1988). And third, an explicit discussion of problems of science philosophy, e.g. with texts from Einstein, Kuhn, Holton and others, can help students to get a feeling of problems about objectivity, truth and the complex relation between theory and experiment in physics. This both helps to become more interested because of a higher intellectual demand and to avoid frustration about not always having "the right idea", which instead of being taught as an everlasting truth also can be seen as the view of today´s physicists. A teaching strategy for explicitly taking science philosophy into physics teaching has been developed with examples in Meyling (1990).

Results of qualitative research on students' epistemological beliefs in high school physics allow to see conditions of learning not only in specific preconceptions of students related to the special topic of instruction but also in their general beliefs and committments about science. A consequence for teaching physics might be to more explicitly discuss epistemological questions embedded into the process of teaching physics.

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