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SCIENCE PHILOSOPHY, SCIENCE HISTORY AND THE TEACHING OF PHYSICS

ABSTRACT: Starting from an analysis of "the new philosophy of science" (Kuhn, Lakatos, Holzkamp) our group has developed a teaching strategy combining student orientation with contributions from science philosophy and history. In addition empirical research has been carried out about students' "matrix of understanding (MOU)" in the fields of mechanics, quantum physics and epistemological beliefs of students. My talk will show examples of the teaching strategy in mechanics and atomic physics. Research results about students' MOU will be presented.

INTRODUCTION: 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 my opinion the basic hypothesis in this field of research is:

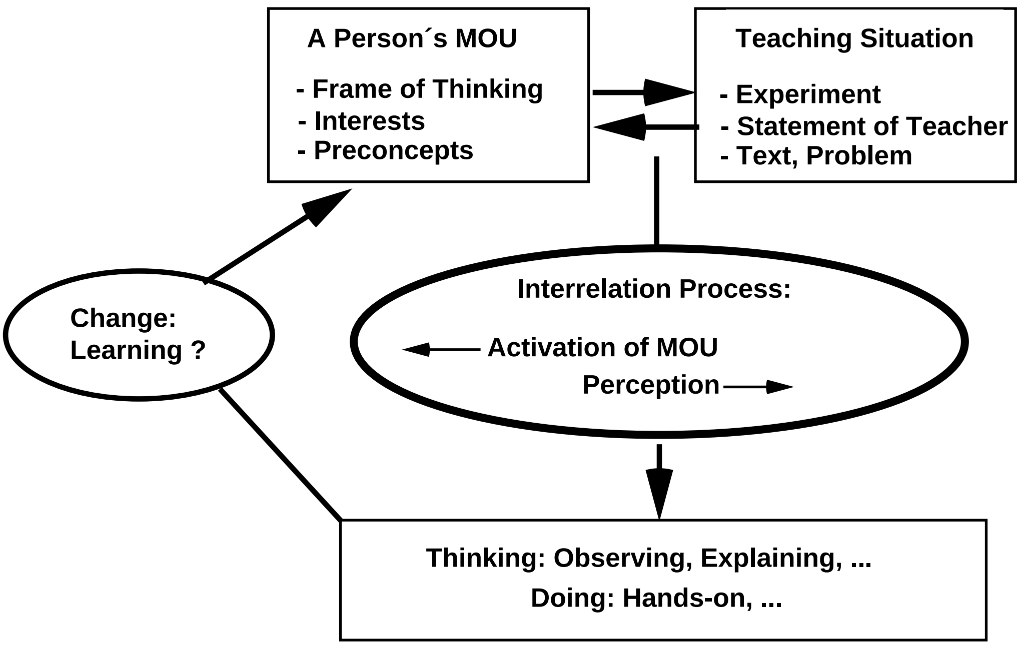
- Learning has to be seen as a process of self-development of the learner, starting with the learner's present view, his alternative framework. There is no direct transfer of meaning (e.g. of concepts like 'heat' or 'force') from teacher to learner! To bring an individual learner to such a self-development 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 constructivist 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 pre-knowledge 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,

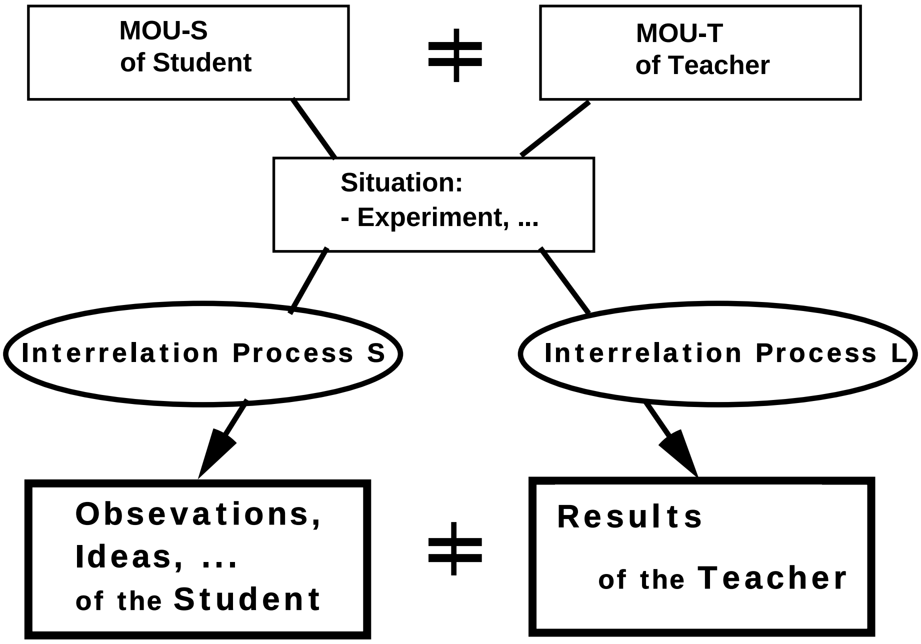


- that the MOU is not a matter of right or wrong ("misconceptions"). Different persons can hold different alternative viewpoints having their positive meaning in a special class of situation contexts,
- that the MOU comprises not only cognitive structures but also the affective domain. In physics teaching 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:



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.

2. SCHEMATIC COMPARISON OF EVERYDAY AND SCIENTIFIC KNOWLEDGE DOMAIN, AND STUDENTS' COGNITIVE SYSTEMS FROM RESULTS OF SCHECKER (1985)

	SCIENCE DOMAIN	**EVERYDAY DOMAIN**	**COGNITIVE SYSTEM OF STUDENTS**
Intention Domain Goals	Construct a *general* theory explaining and predicting many single events	Solve problems in specific *single* situations	Goal of physics: to investigate special situations with sophisticated methods
Language Mathematics	Mathematical language is used to express *generality* of relations for many single data.	Mathematical language is used to give numbers in specific *single* situations and to compute single numbers by using a formula as a computation rule	Formulas as computation rules
Structure of Concepts	Concepts are defined *sharp* and *general*, related to a theoretical schema	Concepts are vague in general but with a sharp and clear meaning in a special context; meaning is depending on context (indexicality)	"Cluster concepts", e.g. force with a vague general meaning being a cause of movements, and specifying this meaning different in different contexts
Relation to Experience and Reality	Doing experiments guided by a general theory, looking only on aspects guided from theory, experiment as "realization" of a theory (Holzkamp)	Looking globally to single situations, taking into account all relevant informations with respect to the purpose of everyday life	Problemsolving by using *special* well known examples together with all their *special* features (e.g. friction) instead of general logical inferences from general concepts

3. STUDENT-CENTERED TEACHING STRATEGY ('LAKATOS STRATEGY')

Central assumptions underlying this strategy are:

a. *Assumption 1:*

The teaching process has to start with own active thinking of the students about a physical problem (experimental situation) on the basis of their present MOU. This phase is sometimes called "elicitation of ideas". It can also be found as an important phase in the proposed teaching strategies of Clement (1987), Driver (1985), Minstrell (1988), Nachtigall (1987), and Osborne (1985). Our strategy goes beyond the quoted authors by proposing that the students must even get the chance to work out own questions and approaches for investigations in a given topic domain.

B. Assumption 2:

The process of conceptual change of the individual can be compared with the process of theory change in the scientific community as described by Lakatos (1970): Unless the new idea comes in **after** having worked with the old concept for a while and thereby having found some weak points in it, there will be no real change.

While Clement constructs "bridging analogies" to lay a direct path from students' alternative views to physics of today, and Minstrell uses elements of students' views to build up the concepts of physics, we do not believe in a guided way, which automatically leads students to the correct concepts.

So in the classroom the physicist's theory has to be offered (by the teacher, by the textbook or by historical texts) after the students have arrived at own conclusions.[1]

The scientific theory has to be contrasted with prior concepts in a kind of negotiation process (Gurney 1988) which explicates the differences between the old (everyday-life) theory and the new (scientific) theory. Context dependent advantages and disadvantages of one and the other theoretical approach should be included in this phase.

These two basic assumptions have led us to the following teaching strategy that was first published in Niedderer (1982) and later on in Schecker (1985) and Niedderer (1987):

<u>Phase 1: Students develop their own ideas about a physical phenomenon</u>[2]

Teacher: introduces a physics topic by

- describing a rough 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

Students: develop on the basis of their own MOU (Matrix of Understanding)

-questions, hypotheses, ideas

-plans for experiments

-results from their own work, formulated in their own words

In terms of Lakatos (1970): *Students develop a first research program **T** with a hard core and a protective belt on the basis of their MOU.*

The teacher does not interfere with students' discussions, acts as a moderator, helps reservedly with technical problems, keeps the students to write down questions, ideas, intermediate results, findings etc.

<u>Transition from phase 1 to phase 2:</u>

Teacher: challenges the students' view by additional experiments.

Students: defend their notions, perhaps modify them slightly.

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1 This seems to be similar to the "input of scientific view" in Driver's proposal.

2 Their "current perspective", Linn 1988

In addition the teacher can present *historical* scientific approaches that are similar to the students' attempts, or he tries to find bridging analogies (Clement) from physics' point of view. This will normally *not* immediately change students' conceptions.

In terms of Lakatos (1970, 116): *No experimental result can ever kill a theory.*

Phase 2: Input of scientific view

The scientifically accepted explanation (concepts and principles) is *offered* as an *alternative view* and compared with the students' elaborated ideas from phase 1.

In terms of Lakatos (1970, 119): *A new theory T' has been proposed. There is no falsification (of* ***T****) before the emergence of a better theory* ***T'****.*

Teacher: explains the scientific theory as an alternative view to the students' ideas - but not as 'the truth'.

In terms of Lakatos (1970, 129): *The experimenter, while testing* ***T****, applies* ***T'****; he interpreted what he saw, in the light of T'.*

Students: compare their ideas with the scientific theory.

In terms of Lakatos (1970, 158): *An experiment is repeatedly performed, T is defeated, T' wins. But the war is not over; any research program is allowed a few such defeats.*

Students and teacher: *negotiate* (Gurney 1988) a common basis that should be characterized by the ability to differentiate between the views and name their advantages/disadvantages in certain contexts.

In terms of Lakatos (1970, 122): *One should try to look at things from different points of view, to put forward new theories.*

Findings from the philosophy of science about the structures of everyday-life thinking and scientific thinking can help to see and accept the differences. The aim is to establish a *deeper, robust understanding* corresponding to a *philosophically sound view* (Linn1988).

In terms of Lakatos (1970, 122): *Sophisticated methodological falsification offers new standards for intellectual honesty.*

The *second* phase implies chances and risks:

- A guided comparison can show to the students structural differences between their concept-systems and the scientific theory as well as specific differences.
- A confrontation with completely different results from the physical theory might disappoint students and lead them to consider their own efforts as useless.

4. EXAMPLE: TEACHING THE CONCEPT OF "FORCE"

We have taught and evaluated the following unit twice in grade 11. Both times the teaching process followed more or less the structure given above.

A. Phase 1: Students develop their own ideas about a physical phenomenon

Preparation:

The students learned the concepts of distance, time, velocity, and acceleration and their measurement in a two months course of kinetics (3 lessons a weak).

Initiation:

The teacher gave a general question (an open problem)

a= f (???)

What does acceleration depend on?

The students were asked to discuss and formulate questions or hypotheses and plan own experiments. They were allowed to use all apparatus available in the physics lab. They should first *write down* their questions/hypotheses and after having done that they were allowed to start with experiments.

Here are some of the specific questions and aims that the groups developed:

- How does acceleration of a small car on an inclined plane depend on its weight?
- How does acceleration of a model locomotive depend on the inclination of the tracks?
- How does the acceleration of a body depend on air resistance? (Students fastened a sail to a small car. This car was set into motion and then braked by an electric hairdryer. Measurement was taken how acceleration depends on the power of the hairdryer and on its distance).
- How does acceleration depend on the surface condition of a road? (For this purpose different sorts of sand were put on the track).
- How does acceleration depend on the height of a car on an inclined plane?

Performance:

The students worked in groups of two or three; they started with discussions and came to formulate questions and/or hypotheses. They thought about possibilities how to realize experiments according to their ideas and sometimes had to modify their goals to make them realizable. Mostly acceleration was determined with the sulphurpowder-method, sometimes by measuring time and distance. Special parts of the apparatus needed (hairdryer, model locomotive, sand, etc.) were provided by the teacher or brought by the students. The experiments lasted three lessons of one and a half hours each.

Afterwards the groups worked out their reports.

B. Transition from phase 1 to phase 2:

Discussion:

Each group gave a brief report; the results were summarized on the blackboard and discussed.

C. Phase 2: Input of scientific view

Comparison with Science:

The teacher told the students that they had arrived at good and useful results (acceleration depending on motor power, power of the hairdryer, inclination of the plane, etc.). Their reports mostly contained measurement descriptions in detail and formulations of results, often using formulas, which contained their *special force!* This aim - as explained by the teacher - is similar to the work of technicians, who are often searching for a *special* formula for a *special* problem. They want to find a technical solution for a single situation. But physicists have a different aim: They want to elaborate a *general* theory relevant for *many* situations. To reach this aim they even invent new general concepts. One is the Newtonian concept of force *defined* as the abstract cause of any acceleration. The meaning of the formulas F = m_a or a = F/m was discussed in relation to the examples of acceleration investigated by the student groups before (meaning, measurement and computation of this general force).

Reflection:

The reflection had already started before: Physics is aimed at general results and corresponding concepts whereas technics - similar to the students' intention - is aimed at solving specific problems in single situations. Another part of the reflection was a discussion about the connection between question, experiment and theory. Some groups had "proved" hypotheses by their data although the underlying hypotheses were wrong.

Schecker in his evaluation of these lessons comes to the following result:

> *"The students found interesting and partially quantitative answers to their special questions. Acceleration was related to special parameters fitting with the special situations: "Power of the hairdryer", "power of the motor", "surface granulation", weight, height of inclined plane, etc. The students were very content with the process and result of their work. They had arrived at special solutions to their special questions. A viewpoint concerning the relationship between acceleration and general concept of force could not be found in the reports of the students. (...)"*

By explicitly discussing aspects of science philosophy the introduction of the Newtonian concept of force was related to fundamental structure of scientific work. In an examination some weeks later some success of this work was evident. The test contained the following question:

> *"Discuss the differences between thinking in everyday life and in physics. Use examples for the formula a = F/m in your discussion. Use the word pairs: exact - inexact, general - specific, defined concepts - obvious concepts."*

The answers of most students were as follows: Physicists search for general concepts, they are not so much interested in special problems. Statements of physicists are less exact in a special situation than those of technicians or of other people. In everyday life we are interested to improve our special actions. The defined concepts of physics are less illustrative than those of everyday language. Experts in physics are often hard to understand when they are explaining something.

Students from this course were eight months later the only ones in a test on general understanding of science (by Schecker) who discussed differences between physics and technics: Physics cannot have a special formula for every process, physics wants to find general rules with general formulas! - The aim of physics is to explain general problems. The aim of technics is to find special formulas!" (Schecker 1985, p. 154).

It seems plausible that this teaching strategy has started a long term learning process by letting students come to own results and by comparing those results systematically with the results of scientific research.

5. THE ROLE OF HISTORY IN A STUDENT-CENTERED STRATEGY OF PHYSICS TEACHING IN THE UPPER SECONDARY LEVEL

We have learned that students are more interested in a historical perspective if they have had the chance to work on the physical problem themselves. So our *major rule* says:

Bring in a historical paper or problem only *after* students have worked on the corresponding problem and have arrived at first results.

If there are parallels between the viewpoint developed by students and some historical approach, bringing in a (short) historical paper can encourage the students in their own attempts and help them clarify their views. It can also be helpful to introduce a historical paper if the teacher knows from research on student's alternative frameworks about latent parallels that have not come out in the present teaching situation. So a *first function of history of physics* is the

- encouragement of students by showing parallels between their intuitive ideas and certain stages in the historical genesis of a physical theory (1).

If the two approaches are completely different, a historical paper from an early phase in the formation of the physical theory can be used to introduce the physical concepts. So students can learn that ideas in physics have historical and sometimes speculative backgrounds and are not merely found by experiments or logical analysis. We formulate as a *second function* the

- introduction of new theoretical approaches after students have developed own standpoints (2).

A. Example: The Photoelectric Effect

This example has been discussed in detail earlier (Niedderer 1986). So I only discuss its relation to the two functions of history:

- Short selected parts from Lenard's paper of 1902 helped students to elaborate and clarify their own approach that the photoelectric effect was caused by some kind of resonance (1).

- Parts from Einstein's paper of 1905 (abridged and translated into modern language) successfully introduced the idea of photons and showed that this approach had some very speculative elements. The students learned that experiments **followed**, not preceded the formulation of the photon-hypothesis (2).

6. EPISTEMOLOGICAL BELIEFS OF STUDENTS IN HIGH SCHOOL PHYSICS

Our physics education research group for many years has been focusing on consequences of studying the new philosophy of science (Popper, Kuhn, Lakatos and others) for teaching. Research resulted mainly 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 statements 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 questionnaires and interviews. High priority in interpretation was always given to those statements of students, which were spontaneous, not direct responses to the teacher's explanations or questions. The process of interpretation is seen as an iterative process in which first hypotheses of elements of students' matrix of understanding come from the theoretical and experience based approach of the study. The process then goes on looking at the data with theses first hypotheses, making changes in the hypotheses, finding new ones, and carefully looking for evidence and counter evidence in the data. Results then are reported formulating the final hypotheses and selected pieces of data giving evidence and/or counter evidence.

A. Physics and Everyday Life

Our general hypothesis derived from work of the German philosopher Boehme (1981) is that there is a general structural difference between thinking in everyday life and in science.[3] Whereas in science we want to arrive at *general* theories for many different kinds of situations and problems (consistency) and therefore use 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 broad concepts vaguely defined in general (force) but with a context specific meaning in the special situation they are used. In our empirical studies e.g. on force we found exactly this type of concepts used and called them "cluster concepts", that means concepts vaguely defined in general but with a cluster of different special meanings in special situations.

The following more special results about students epistemological beliefs (Schecker 1985) are supposed to be a consequence of this structural difference:

B. Transformation on Realizations

- Students tend to transform problems that are meant as abstract thought-experiments on imagined everyday-life experiments: "What would happen if the experiment was really done?"
- This leads to a re-interpretation of tasks, taking into account those conditions which were meant to be neglected, e.g. friction effects
- Students resist against "unrealistic" abstractions in the teacher's reasoning.

[3] see part 2. above.

C. The task of physics

- The subject matter of physics are phenomena from the everyday life world. Physics gives precise explanations for single phenomena closely related to direct experience; the relevance of physics is not so much seen in giving generalizable theories.

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

Students understanding of central concepts of philosophy of science

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 which may change in time

An *explanation of a phenomenon* is given by

- a description or clarification in a model or a theory
- describing the cause of the event or phenomenon
- relating it to well known and accepted laws or theories
- an exact description of reality as it actually is

Hypothesis and theory

- Hypothesis and theory are synonyms; theory is preferred.
- A hypothesis is a guess which, after being tested and approved, becomes a theory
- A theory is far removed from reality, of little practical value
- Theories are used for explanations, not for predictions

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*.
- sometimes taken for reality; the limitations are not clear.

Students' understanding of the scientific process

(Alternative conceptions referring to different groups of students and different states of the learning process.)

Rationality of processes

- Speculation and intuition have a negative meaning; they are of little value for science
- 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

The meaning of experiments

- Students like to do 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
    - an experiment
    - a hypothesis
    - an observation
- The end point of science is
    - a basic law of science
    - a theory

Interests of students

- Students are very interested in "reality". (This reality has to be discovered by science.)
- Students are very interested in explanations of phenomena, observations of everyday life and technical processes.
- Students are very interested in technical applications of physics.
- Students are not so much interested in
    - history of physics
    - discussing issues of philosophy of science in physics.

7. SUMMARY

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 commitments 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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