PS2-D-Symp

Symposium:
The integration of students' preconceptions in physics instruction: overcoming the hurdles

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Discussant: D. Psillos, University of Thessaloniki, Greece

"The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." Ausubel's quote from 1968 gives a frame for a main research focus in science education of the last three decades: Students' preconceptions in numerous various science topics were investigated in the seventies and eighties. In the following years several models of a constructivist approach in science teaching and learning were developed. In all of these theories the integration of students' preconceptions plays a key role.

At our symposium the results of three research projects are presented: In all of them the integration of students' preconceptions is investigated in physics instruction at the upper secondary school. The research projects, whose methodological approaches are quite different and – in this sense – typical of the broad spectrum of methods in science education research, are 1) a case study of the learning process of a single student, 2) the description of two teaching situations on a modelling approach, 3) a broad quantitative study.

1) Hans Niedderer and Jürgen Petri describe the relations between teaching and learning in a quantum atomic physics course. The whole teaching process followed a contrastive teaching strategy and was totally videotaped. The analysis of the learning process of one single student gives examples for contrastive teaching and for the integration of students' preconceptions.
2) Jean-François Le Maréchal, Christian Buty, and Andrée Tiberghien discuss – in reference to a modelling activity – two kinds of teaching situations that have different functions in typical learning processes in science: I) Introducing a new domain – a seed of a theory / model, II) Extending the field of applicability of the seed of the model and/or extending the model.
3) Peter Labudde presents the results of an empirical study that was added to and embedded in the Swiss part of the "Third International Mathematics and Science Study (TIMSS)". His data show that the students see an integration of their preconceptions only seldom. The results also indicate that an integration would be worthwhile as it is significantly correlated with motivational variables and – to a lesser extent – with students' knowledge in physics.

Dimitris Psillos, physics educator and researcher in physics education, summarises and discusses the three presentations. He points out future research lines with regard to the integration of students' preconceptions and to the learning of physics in general.

As the contributors and the discussant are from four different European countries, this symposium has a really international perspective and offers the chance of a broad exchange of research methods, theories, and empirical results.

PS2-D-Symp

An empirical study analysing the status quo, the efficacy, and some problems of the integration of students' preconceptions

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Abstract.
How often are students' preconceptions integrated in daily physics instruction? What is the efficacy of an integration with regard to motivational variables, students' physics knowledge, and their images of science? In an empirical study, added to the Swiss part of TIMSS, 671 students in grade 13 answered a questionnaire. The data indicate that students' preconceptions are seldom integrated. Nevertheless this would be worthwhile as there are significant correlations between an integration and motivational variables and – to a lesser extent – students' physics knowledge.

Introduction.
Students' preconceptions, also called alternative frameworks, have been one of the main research foci in science education in the last three decades: In the seventies and eighties students' alternative frameworks were evaluated in numerous science topics (Novak 1987 / 1993; Pfundt & Duit 1994). In the following years several theories and models of a constructivist approach in science teaching and learning were developed. All of them included – as a key factor – the integration of students' preconceptions (e.g. Driver 1995, Duit 1995, Duschl 1990, Fensham et al. 1994, Gil-Perez 1996, Roth 1995). The idea and the importance of this integration are widely accepted, although there is still a lack of empirical studies that would support this idea sufficiently. The main research questions of this paper are:

- How often are students' preconceptions integrated in daily physics instruction?
- What is the efficacy of an integration with regard to motivational variables, students' physics knowledge, and their images of science?

Design.
For the learning in a constructivist sense it is crucial how the student experiences a situation. This is the reason, why we decided to ask the learners how they see physics instruction and the integration of their alternative frameworks. We developed a questionnaire for students at the end of grade 13 of a "gymnasium", the cognitively most demanding track in Switzerland, leading to university studies. In this kind of school all students have to take physics courses.
The questionnaire was added to the questionnaires and tests of the "Third International Mathematics and Science Study (TIMSS)", i.e. our research project was a national in-depth-study embedded in TIMSS (Mullis et al. 1998). 671 students of 152 classes, i.e. 4-5 students of one class, who were part of the Swiss TIMSS-sample, answered our questionnaire, the international TIMSS-questionnaire, and a TIMSS-physics-test. This research design offered the chance to participate in a broad international study, to have a representative sample, to use simultaneously different instruments, and to combine international and national data.

Procedure.
The theoretical frame of our study is a constructivist approach of science learning

and teaching (Labudde 1998). Within this theoretical frame we developed a pilot-questionnaire that was pre-tested together with the instruments of TIMSS in 1994: 90 randomly chosen students of 28 classes answered our pilot-version. The reliability analyses of the data and theoretical considerations led to a revision of the pilot-questionnaire.

The final version included 224 items, most of them were part of one of 27 scales. These scales belonged to six different topics: 1) the individual dimension, 2) the content dimension, 3) the social dimension, 4) the dimension of teaching methods, 5) motivational variables, and 6) students' images of science (Labudde 1998, Labudde & Pfluger 1999). As the focus of this symposium is on students' preconceptions we concentrate on the individual and the contents dimension (1/2), and on correlations between these dimensions and motivational variables and images of science (5/6). The scales that are discussed in our talk are:

- *Individual dimension:* integration of pre-knowledge, physics as an experience;
- *Contents dimension:* physics and everyday life, physics and society;
- *Motivational variables:* popularity of physics, self-confidence in physics, benefit of physics for other school subjects and for everyday life;
- *Images* of *science:* "truth" of physics, continuous changes in physics, problem solutions in physics, co-operation in physics.

As an example the scale "integration of pre-knowledge" is noted in the following table. This scale includes 6 items. The four answer categories were: (1) "agree", (2) "almost agree", (3) "almost disagree", (4) "disagree". A reliability analysis of the data of the main survey yielded for this scale a Cronbach-alpha of 0.72.

Scale "integration of pre-knowledge" (6 Items, N=606, Cronbach-Alpha 0.72)	Mean (1: agree, 4: disagree)
The teacher integrates our experience of everyday life in the physics instruction.	3.05
When we start with a new topic, the teacher asks what we already know about it.	2.97
When a new concept is introduced, we discuss relations and/or differences between the physics definition and the corresponding everyday world.	2.79
The teacher asks us to relate laws and theories of physics with our experiences from everyday life.	2.50
When a new concept is introduced, we reflect what we already know about it.	2.36
Experiences from everyday life help me to understand physics problems at school.	2.35

The main survey took place – together with the TIMSS main survey - in 1995. Our sample of 671 students is (almost) representative for the German speaking part of Switzerland. The sample included 46.1% women and 53.9 % men; their age was 19.6 years on average.- The analysis of our data and of the international TIMSS data was done using the standard software of SPSS (version 6.11).

Data analysis and findings.

What is the status quo of the integration of students' frameworks, i.e. the realisation in daily instruction as seen by the learners? Our interpretation of the mean values is that students see an "integration of pre-knowledge" seldom to medium (see table above), "physics as an experience" seldom, relations between "physics and everyday life" medium, and relations between "physics and society" seldom (see table below). In particular, young women significantly less than young men see "the integration of their pre-knowledge" and "physics as an experience"; the relations between "physics and everyday life and society" are less obvious to them than to their male colleagues.

This result confirms the findings of other gender studies (e.g. Labudde et al. submitted, Parker et al. 1996).

Dimension	Scale	Realisation in daily instruction	Motivational variables			Physics knowledge (measured by TIMSS)
			Popularity of physics	Self-confidence in physics	Usefulness of physics	
Individual	Integration of pre-knowledge	Seld.-Med.	0.19***	0.21***	0.36***	0.08+
	Physics as an experience	Seldom	0.38***	0.41***	0.46***	0.17***
Contents	Physics and everyday life	Medium	0.18***	0.23***	0.40***	0.02
	Physics and society	Seldom	0.18***	0.20***	0.37***	0.01

Level of significance: ***: p<0.001, **: p<0.01, *: p<0.05, +: p<0.10

There are several significant correlations between the four scales representing the integration of students' frameworks. The Pearson-coefficients are much higher for the motivational variables than for the physics knowledge as measured by the TIMSS-physics-test. "Physics as an experience", i.e. the affective involvement of the students, has the strongest correlations of all. There are no correlations between the four scales and any scale dealing with students' images of science (Labudde 1999).

Conclusions.

The questionnaire and its scales proved to be a reliable instrument to measure different facets of the integration of students' preconceptions. In daily physics instruction this integration is seen by the students seldom to medium, for women even less than for men. There are significant correlations between the integration of preconceptions and motivational variables, but only week correlations with students' physics knowledge. Our results lead to further research questions: Why do many teachers not integrate students' preconceptions? What would be the correlations between the integration of preconceptions and other types of examinations than the TIMSS-test? Which educational parameters correlate with students' images of science?

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Teaching situations based on a modelling approach

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Abstract.
In reference to a modelling activity, there are several kinds of teaching situations which have different functions. In this communication, two kinds of situations will be presented. The first kind is at the beginning of a teaching sequence; such a kind of situations aims at introducing a new domain. This situation is carefully designed in order to constraint the students to take into account a seed of a theory / model and to go back and forth between this theory / model and the experiment. The second kind of teaching situations involves the student in the construction of new concepts or new facets of concepts. In this kind of situations, even if, as in usual teaching, the mathematical modelling like in physics, or the observation like in chemistry are involved, the tasks require to take into account the relations between the concepts and the objects / events of the experimental field.

Teaching situations are very complex objects of study (Laborde, 1997). They imply socio-cognitive processes involving teachers, students and knowledge. Although science teachers intuitively daily create teaching situations all over the world, the rational design of teaching situations is a difficult enterprise. These situations should be designed in order that students can acquire physics or chemistry and then should, *ad minima,* take into account all the studies on students' conceptions. These studies show how, most of the time, conceptions are far away from physics approaches which points out one of the major design difficulties. A further complication arises from the fact that little is known in the different cognitive functions of a concept (Reif 1992). We choose to work out the complexity of the description of teaching situations, taking into account two main aspects of experimental sciences: modelling and experience. With this in mind, designing a teaching situation reduces to create sequences of activities aiming at helping *students to construct an understanding of the* *relations between theory/model and experiments* (Tiberghien, 1994). A teaching sequence on a domain in a given academic year usually lasts for two or three months (20 to 40 hours about). The succession of teaching situations implies diverse ways of involving modelling. We will present these different ways based on several domains : energy, sounds and optical geometry in physics and aqueous solutions in chemistry. The series of situations are based on the following assumption : the content of the scientific information given to the students should be understandable enough to be used to construct an interpretation of the given experiment (or series of experiments).

Introducing to a new domain: a seed of a theory/model.

This first kind of situation takes place at the beginning of a sequence. A text, experiments and questions, which are given to the students, are carefully designed in order to constraint the students to go back and forth between the theoretical elements and the experiment. In particular the aim of the text presenting a seed of the scientific theory/model is that the students construct a first meaning of the basic theoretical rules and use them to elaborate an understanding of at least a few experiments. Most of the time, in order that the students construct this meaning, they have to learn:

- *a new way of observing the experimental field*: the objects and events which are pertinent for the theory / model and
- *relations* between the objects and events pertinent for the theory / model and the new concepts or rules.

For example in the case of energy, students need to consider as relevant facts, with the experiment of a battery and a bulb, that the bulb shines and heats, that is gives light and heat. They have to associate the bulb to a transformer of energy from electrical work to heat and radiation.

In the case of sound teaching, the students have to learn that, when they hear a sound, an object and its environment until his/her ear necessarily vibrate. This mechanical phenomenology is a necessary learning step to understand the physics modelling of sound. This phenomenology is associated to elements of theory / model such frequency and amplitude.

In the case of the chemistry of ionic aqueous solutions, a key observation of the experimental field (the test tube with the solution) is the fact that the chemicals in the tube end up to be either a clear solution or a suspension (liquid + non soluble solid). Such an observation is of importance for the precipitation reactions, for the filtration steps,... In the case of the mixing of two ionic solutions, the formation of a precipitate (experimental fact) is an indication that at least a cationic species **and** an anionic one has reacted (theoretical interpretation).

A seed of a theory / model makes possible:

- a communication dealing with the new domain between students and between the students and the teacher,
- to raise new questions relevant for the domain under investigation and then new problems and experiments.

It has some common characteristics whatever the scientific domain.

It is elaborated under several constraints which may be contradictory. On one side this theory / model should respect the scientific information, should respect the official curriculum and on the other side to be understandable by the students and manageable by the teacher. We share the learning constructivist hypothesis that the students can only learn from what they already know. Then in case of all those constraints cannot be respected simultaneously, we choose that the main one is "to be understandable by the students" (Tiberghien, 1997). This orientation implies to use either words which belong to the students' vocabulary or to define some words; it also implies to use a causal reasoning compatible with the students' reasoning.

This seed introduces a new specific lexicon (vocabulary) associated to the basic concepts necessary to take up the domain and more particularly the selected experimental field. This needs a deep analysis of the scientific content involved, in order to select the primitive concepts of the theory. This also needs to make hypothesis on students' knowledge.

In the case of energy, the seed of the model is based on the primitives corresponding to the three main properties of energy : storage, transformation, transfer and on the conservation principle. A specific vocabulary is introduced to specify the mode of energy transfer : heat, electrical and mechanical work, radiation which can be transformed. The choice of being understandable leads to introduce energy as a primary physical quantity and not as a relation quantity. This choice leads to a distance between this seed of model and the scientific knowledge but is done to make this model understandable and usable by the students.

In the case of geometrical optics, the seed of the model is based on geometrical primitives, line, angle, point. This allows the introduction of the physical concepts such as ray, beam, object. The laws of reflection and refraction come next on the seed of the model.

In the case of ionic solutions in chemistry, the seed of the model is based on few electrostatic concepts: positive an negative charges, electroneutrality. The model introduces solubility concept, experimental criteria of solubility and relation between solubility and precipitation. Precipitation is defined as the result of the association of positive and negative ions which paves the way to future introduction to chemical reaction.

Extending the field of applicability of the seed of model and/or extending the model.

Such aims could seem similar to those in the usual teaching particularly for experimental activities (labwork). Comparison of usual labwork sheets with a tool called « map » (Millar et al., submitted; Tiberghien et al., submitted) reveals significant aspects. From usual labwork sheet, the authors noted: " [...] in physics do many labwork sheets ask students to ‘explore the relationship between physical quantities'. Also in physics, more often than in chemistry or biology, the students are asked to 'account for observations in terms of a given law'. This may reflect the higher prominence of mathematical modelling of relationships between variables in physics than in the other two main sciences".

As far as chemistry is concerned : "The two most common categories for chemistry are ‘direct reporting of observation’ and ‘determining the value of a quantity which is not measured directly’. [For all disciplines], they seldom have to explore relationships between objects, test a prediction, choose between two (or more explanations) or construct a new concept (or entity). Even at university level, it is rare for students to have to test a prediction from a guess or from a theory".

In usual teaching, whatever the experimental disciplines, the variety of activities is very small: in physics the mathematical modelling is the main activity whereas in chemistry it is observation. However a modelling activity, essential in experimental sciences, implies to relate observations of the experimental field to measurements or mathematical modelling, it appears that this kind of activity is very rare in usual labwork.

This analysis leads us to several choices. When extending the seed of a theory / model, in physics, the mathematical aspect of the model is far from being essential. We do not systematically avoid the mathematical modelling which can be inherent to the physics or chemistry knowledge to be taught. We aim at developing a variety of activities giving the students the opportunity to establish links between the physical concepts including the mathematical relations in one hand and the objects and events of the experimental fields in the other one. It is necessary, in comparison to the "seed" of the theory / model, to help the students to increase the thickness of the model.
Recent studies (Bécu-Robinault, 1998, Leach, 1998, Sander et al., 1998) show the high cognitive cost of such relations. The students relate model and experimental field only if they are explicitly requested to do it or more generally if the task constraints them to do it. Consequently, due to the duration of some activities like making measurements and due to the cognitive costs of activities at the level of the theory / model (processing measurements, relations between quantities, etc.) and of activities relating model and experimental field, we consider that several steps corresponding to *different* typical teaching situations are necessary. We propose different typical situations for extending the model, and for establishing links between this extended model and the field of applicability. We will particularly develop the third one by giving some typical tasks which allow students to relate model and experiments.
The third kind of teaching situations which will not be developped here involves the whole domain, that is the target of the teaching sequence. The situation uses experimental and/or problem solving and requires that the student links the concepts introduced in the preceding situations.

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Relations between teaching and learning in a quantum atomic physics course

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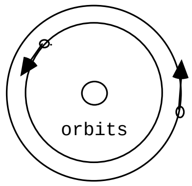
Abstract.
The learning process of a single student in a quantum atomic physics course has been analysed with respect to his conceptions of the atom. The whole teaching process followed a contrastive teaching strategy and was totally captured on videotapes. Additional analysis of data was done to analyse the relation between teaching and learning. The teaching process (alltogether 80 lessons) consisted of classical teaching of different length (lectures from the teacher, informations from texts and other media), group work for 10 to 30 minutes and small projects for 3 to 5 lessons. The analysis of the data gives examples for contrastive teaching, and for integration of students' preconceptions. Effects of different parts of teaching on the learning process are described. These results are discussed in relation to the general problem of teaching strategies as pointed out by the international TIMSS study and some expert suggestions based on these results.

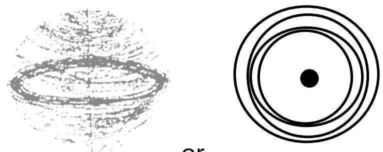
Learning processes.
This paper is based on results of a case study, in which we analysed an individual student Carl's learning pathway in a course on quantum atomic physics in grade 13 of a German gymnasium (Petri 1996, Petri&Niedderer 1998).
Our general aim was to elaborate the student's cognitive system for atomic physics as a hypothetical pragmatic model to describe, analyse and explain his thinking and learning in interaction with the teaching input. Carl's learning pathway is described as a sequence of several meta-stable conceptions of the atom, starting from a planetary model.

Contrastive teaching strategy.
The teaching strategy used in this teaching approach enables students to elicit their ideas and express them freely in class before and after a new science concept is introduced by the teacher. We use the term *contrastive teaching* in a learner-directed approach to idicate the important role of two interrelated phases: to introduce a scientific view with scientific concepts by the teacher or teaching materials and to let students work with their own ideas, their own questions, and their own conceptions.

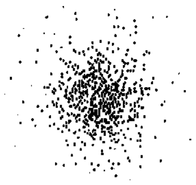
We hypothesize that, as long as students are not aware of their intuitive notions, they hardly will be able to learn a related scientific concept. For example, most students have a planetary model of the atom with electrons moving around the nucleus on orbits. However, considerable teaching effort is required to help students notice the differences between their intuitive views derived from everyday experiences and the scientific view based on theory-laden observations in quantum physics. (Schecker&Niedderer 1996).



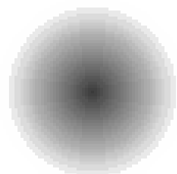
Carl's first conception of the atom
- the planetary model



or
Carl's second conception of the atom
- the probability orbit model



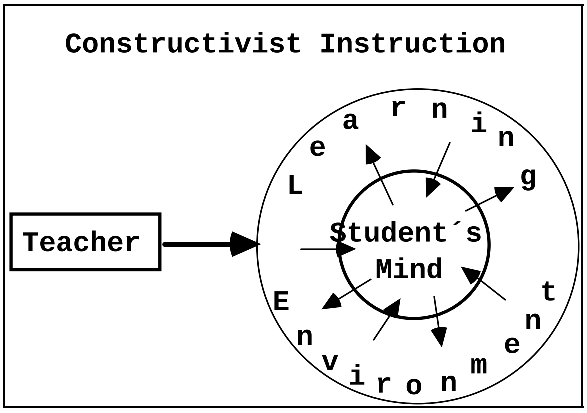
Carl's third conception of the atom
- the state-electron model



Carl's fourth conception of the atom
- the electron cloud model

The relation between teaching and learning.

The contrastive teaching idea perfectly relates to learning principles as formulated by Wolze (1989).



In his book, from a theoretical perspective, he analyses learning as a developmental process which has two complementary aspects: self-development of the cognitive system based on dynamic processes inside the cognitive system on the one hand, and a developmental process more determined by the influences from outside from the learning environment - "being developed" - on the other hand.Thus learning is a developmental process inside the cognitive system of students, which cannot directly be influenced by the teaching input. The figure above is illustrating this situation. So the relation between teaching and learning is complex. We use the following ideas to analyse it:

- In some cases we find evidence of resonance between what is taught and what the student actively reconstructs (von Glasersfeld 1992).
- We show examples how scientific concepts and content is contrasted with explicitly formulated ideas of students, which are wellknown preconceptions.
- Our empirical results in some cases give evidence that students have constructed what we call intermediate conceptions during teaching, which were never intended by the teacher or the instructional materials. In these cases we are sure that the main effect is self-development of the cognitive system based on its preliminary

cognitive tools.

- Finally we analyse some dialogues between teacher and students as a form of proximal development in which students are assisted in their own cognitive development by the teacher, thus reaching higher levels of conceptual structures in the "zone of proximal development" (Vygotsky 1978). We compare these dialogues with group work related to the same content area, where students work on their own ideas without help of the teacher. We relate this to Vygotsky's level of "actual development".

Data.

The following data were used for the analysis:

- observations and a pre-questionnaire about students' conceptions of electrons and atoms, about their world view and their view about physics in weeks 1 to 4.
- videotaping the total teaching process of about 80 lessons and the group work of four students in weeks 5 to 16.
- spontaneous short interviews during group work in class in weeks 5 to 16.
- semi-structured interviews in small groups for about 20 - 30 minutes.
- semi-structured final interview with all students for about 30 minutes.
- semi-structured interview with some students 3 months after the end of the teaching period, for 45‘.
- written materials of each student from the class in weeks 5 to 16 (protocols of work, written examinations, written homework, about 300 pages).

Findings.

Integrating preconceptions into teaching is analysed with classroom discussions in which the most frequent and stable preconception of students of the atom - the planetary model - is compared and contrasted with a new quantum model, which doesn't tell anything about orbits, but more about distribution of the electron in three-dimensional space. We discuss an example for resonance in which students in lecture as well as in group work cope with screening effects of inner electrons in higher atoms and by following this problem come to a clearer conception of electron distribution and even electron charge distribution ("electronium"). Examples of intermediate conception are "smeared orbits" and "the state electron" (see above). With the idea of proximal development we show an example about understanding the hydrogen plus molecule, where formal, passive learning with assistance from the teacher (zone of proximal development) changes to own constructions of the student (actual developmental learning).

General interest.

Finally we want to discuss our results in the context of discussion about teaching strategies in Germany and Japan which started from the TIMSS study. We believe that this kind of "contrastive teaching strategy" which was described, is a better alternative than what is very often used in German schools and is called "fragend-entwickelnder Unterricht", a teaching strategy where the teacher poses narrow questions, answered by one student, followed by small additional informations of the teacher etc. This teaching strategy very rarely allows for students' own and independent thinking and construction of concepts and ideas.

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