Third Misconceptions Seminar Proceedings (1993)

Paper Title: Misconceptions as indispensable steps toward an adequate understanding of physics

Author: Fischer, Hans E. & Breuer, Elmar

Abstract: This paper will explain difficulties of students during their learning of physics and it will make a proposal to describe students' starting points of adapting the physicist's "true" concepts. Let us start with a characterisation of the term "misconception". To be able to decide if a conception is a misconcept or not the standard has to be the expert's knowledge. As a matter of fact most of the investigations about misconceptions are based upon not only the expert's knowledge but the expert's way of learning, too. Under the headline: what is good for an expert must be good for a student, many units, teaching strategies and so called learning strategies were created which propagated a better way of learning physics. As we understand now there is no best way of learning physics in general. If we go into detail, we have to state that there are many ways of learning physics and that we are able to identify classes of learning pathways which are miles away from the "ideal" one of an expert. Maybe that the first not very deep going description of learning processes gives us some evidence for the existence of misconceptions. But what happens if we use another theory about learning as a microscope? Theories about the individual constructions of knowledge lead us to a point of view which takes the observed student's aims of action as standard, not the expert's. Describing learning processes leads us to categorize types of learners. It is obvious that those categories have to have their roots in a theory about learning in general and not about how an expert solves given problems. One of those theories will be outlined in the following:

Keywords: Learning Processes,Comstructivism,Qualitative Methodology (hermetic content analysis),,,,,,
General School Subject: Physics
Specific School Subject:
Students: grade 10,11 high school

Macintosh File Name: Fischer - Physics
Release Date: 12-15-1993 C, 11-5-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993

Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

----- -----

Misconceptions as indispensable steps toward an adequate understanding of physics

Hans E. Fischer & Elmar Breuer, University of Bremen, Germany

Introduction

This paper will explain difficulties of students during their learning of physics and it will make a proposal to describe students' starting points of adapting the physicist's "true" concepts. Let us start with a characterisation of the term "misconception". To be able to decide if a conception is a misconcept or not the standard has to be the expert's knowledge. As a matter of fact most of the investigations about misconceptions are based upon not only the expert's knowledge but the expert's way of learning, too. Under the headline: what is good for an expert must be good for a student, many units, teaching strategies and so called learning strategies were created which propagated a better way of learning physics. As we understand now there is no best way of learning physics in general. If we go into detail, we have to state that there are many ways of learning physics and that we are able to identify classes of learning pathways which are miles away from the "ideal" one of an expert. Maybe that the first not very deep going description of learning processes gives us some evidence for the existence of misconceptions. But what happens if we use another theory about learning as a microscope? Theories about the individual constructions of knowledge lead us to a point of view which takes the <u>observed student's aims</u> of action as standard, not the expert's. Describing learning processes leads us to categorize types of learners. It is obvious that those categories have to have their roots in a theory about learning in general and not about how an expert solves given problems. One of those theories will be outlined in the following:

A theory about learning

Our thesis is that every cognitive development has to start from a low level and it is related to its own past and not to its future. Even the future oriented <u>aims</u> of a student's activity are constructions based upon already existing structures. They are situation dependent and part of recently activated cognitive part systems. To describe learning processes we follow up how a student's meanings of objects and its properties or more complex cognitive construction of situations develop during instruction. Especially in the school of Piaget "meaning is not regarded as an inherent property of things but as being generated by the individual" (Piaget 1978, 153). Therefore meaning cannot be transmitted to the individual from things, a situation or another participant of a communicative process but it is generated by the interacting individual on the basis of his already developed conceptual abilities (for example the ability of concrete operative thinking). Beneath those conceptual abilities there is no hierarchically ordered higher authority within or outside the individual to judge and order new perceptions and to organize the action in a new situation. As early as 1926 Piaget described the development of thinking from an early age animism to a developed and independent identity of an individual. In this description the interaction of the intelligent organism with reality is regarded as the origin of "knowledge"[1]. The main element of his theory is not the comparison of cognitive constructions with reality but the success of cognitive constructions (their viability) when they are used to organize behaviour. As a result of the interpretation of the clay-ball experiments performed in 1969 by Piaget and his co-workers, it was possible to describe children's' cognitive development towards an "invariant matter". The degree of the produceable invariance was connected with the context dependent perception of the child: "Perceivable facts (gain) meaning only through assimilation in the context of repeating actions." (Piaget/Inhelder, 1969, p. 386. Authors' translation).

To describe such a process, Piaget introduced the concept of "pattern of action". The patterns of action are regarded as instrumentalistic structures, judged according to their viability during individual interaction. Standard of the viability is the equilibrium of the organism. This central element of the Piagetian theory about learning processes was developed further by Glasersfeld (1989) in the framework of a constructivist theory about cognition (Fischer 1993). Another idea helps to assess the relevance of "misconceptions":

Lawler (1981, 2) and Bauersfeld (1983) emphasized that cognitive structures generate context dependent and domain specific. So-called "domains of subjective experience (DSE)" are regarded as individual organizers of the action of a subject. Bauersfeld demands four necessary abilities of a DSE:

---

1 Piaget does not use the term "knowledge" interactionistically in the sense that, after the first interaction and with the newly developed knowledge, reality will be reflected better than before.

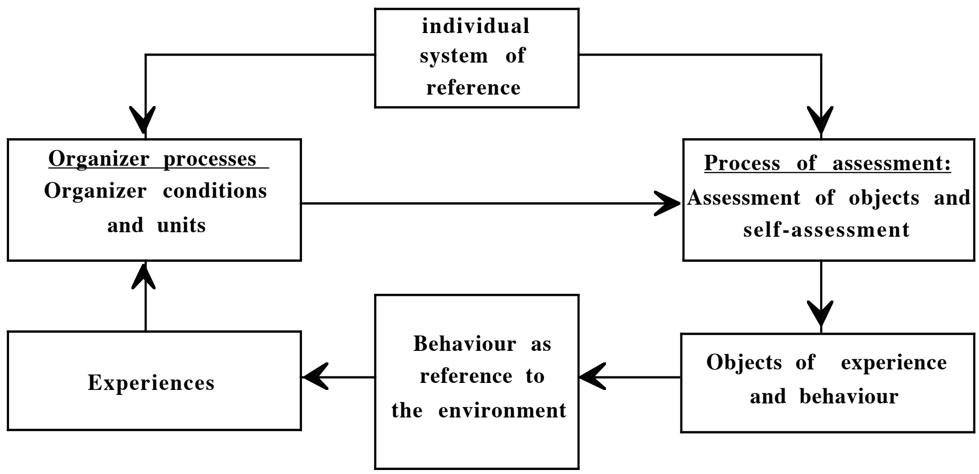
1. Among others, one DSE is a part of the cognitive system.
2. The development of a DSE occurs context-dependent.
3. A DSE can be seen as the holistic starting point for an individual to perceive a situation and to initialize interaction. Therefore, in the beginning of its generation a DSE is closed and fixed upon the more or less complex class of situations in which it is generated.
4. During the further development the just generated DSE becomes more and more modified and linked with others.

This implies that learning processes can only be analysed adequately during instruction, "if the intensive integration of every individual activity into social interaction" (Bauersfeld, 1983, 38. Authors' translation) has been considered.

Misconceptions

So what about misconceptions?

we claim that, at the beginning of a physical teaching unit at school, or in other words at the beginning of the generation of a new DSE the used conceptions of a student have to be "wrong" if they are seen from an expert's description of the aim the student might reach. There is no other chance because the new, complete and correct expert's concept cannot be transferred from the teacher to the student. Every new DSE is only based upon the history of the cognitive system and not upon its future. Thus, every student tries to organize his interaction by using the most viable conception he ever has constructed before. This conception has to correspond to the student's construction of the situation. Thus, this construction is determined by the student and his system of reference and it is initiated by the student's reaction to signal inputs of the environment. we don't want to talk about how an individual system of reference comes into being but we will show you a model to describe the feedback process between interaction, perception and learning, which might be able to explain learning pathways:



Picture 1:
Model of a cognitive system. It contains units with different functions which develop in a self-referential process modified by sensitive couplings with the environment.

We take the existence of a *system of reference* as part of the whole cognitive system as granted. This assumption corresponds with newest outcomes of neurobiologists. They tell us that the limbic system of the human brain seems to be such a system of reference. It has its main function in organizing or modulating other areas of the brain. The mechanisms and functions are not yet very good explored but it is evident that there are global influences by means of chemical and physical mechanisms. The behavioural results of those processes are called emotions, feelings, attention etc. The whole system of these characters develops very slowly to grant the preservation of the individual's identity. Therefore, we have no chance to observe any development during our three or four months of investigation at school but probably we are able to find its current state.

Organizer conditions are recent and *organizer units* already made experiences. The discrepancy between both and their assessments is seen as the determining condition for learning and behaviour. Therefore, the *process of assessment* is to be seen as main reason for the emergence of meanings as *objects of experience and behaviour* (Fischer et al. 1993).

Regarding the above context of an individual system of reference we can take "misconceptions" as those conceptions which are not able to organize the activities of a corresponding situation in a satisfying way. But on closer inspection we find that there is more than one reason for a cognitive system to produce "wrong" or inadequate reactions:

- The situation is new. In this case the interactive reaction is the result of the activation of old cognitive part-systems but partly also of new connections between them. The discrepancy between organizer conditions and organizer units is decisive to organize the ongoing interaction and to modify the activated cognitive part system. In all probability the cognitive construction and the resulting interaction is inadequate.
- Maybe the students perceive the situation or parts of it as well known. In this case the inadequate reaction results in activating very strong patterns of cognitive connections. They have proved to be viable in former situations. In those cases the situation is misunderstood. There is no or only a small discrepancy between organizer conditions and organizer units and thus no need for a change of the cognitive part system or the interaction.
- In another case two alternative cognitive patterns may compete and the inadequate solution wins by chance. The discrepancy and the resulting changes differ from case to case. We assume that many of the students' interactions start with an ambivalent state of their cognitive conditions.
- In another case the adequate construction of a student may fail and, as a result, an adequate reaction is impossible. The discrepancy is too big to cause a change. The student gives up and in the best case, he or she tries to find a new starting point.

As a result of all the above possibilities, when the environment is able to make the inherent discrepancies of the situation explicit, a learning process may be initiated. Even in the fourth case a (negative) learning process can be expected. The adequate pattern will, for the first, not be activated in similar situations.

The common character of the four above situations is the existence of a situation dependent discrepancy and not of a stable "misconception". We state that discrepancies between organizer conditions and organizer units are a global property of cognitive systems and the only reason for them to change.

Another global property of a cognitive system is its self-organisation. The permanent flow of connecting and disconnecting more or less large units of activity contains knowledge and includes the necessity of stating similarities and comparing alternatives. Therefore, to analyse learning processes we have to analyse the interactive context and we must describe if the acting individual assesses his or her own ideas as adequate or not.

In this context misconceptions (which refer to an expert's cognitive system) are seen as an expert's comparison between a student's and an expert's interaction or problem solving abilities in a certain situation. What we do in the best case is to compare two cognitive systems which are not comparable because their genesis is totally different. Therefore models based on the hypothesis of "misconceptions" are not viable to understand students' learning processes and therefore the results regarding teaching strategies and learning environments are only small.
In the following we will present short periods of students' activities to give you an example of wrong ideas which are nevertheless able to lead to a proper understanding of electrical charge and one example of the result of lack of a physical explanation.

Physically inadequate ideas

In all of our case-studies on students' learning during activity and communication oriented instruction in electrostatics we found situations in which students use physically inadequate ideas to organize their own activities. We are able to observe how those ideas change within the tension between own experiments and the interactive feedback (communication and co-operation) which occurs. Ideas can be seen as inadequate from an expert's point of view but nevertheless they can be able to organize the student's action during a recent situation until the aim of the activity is reached (or not). When the situation ends, the discrepancies between organizer conditions and organizer units can be the starting point to construct a new aim of action and a new situation organized by changed but maybe nevertheless inadequate ideas. At the beginning of the instruction the observed student is able to communicate about charge or about charging an object on a less elaborated level. At the end of 30 lessons he seems to know how a physicist would talk about it. But even the student's ideas at the end do not withstand a deeper consideration of an expert.
In the following, we will use the term "ideas" related to the student's situative context. The terms "misconception", "adequate" and "inadequate" are only used if the described ideas refer to an expert's view.

Background

The first two examples are from an electrostatic unit in grade 11 of a high-school. Aim of the unit was to discuss a field concept of force transition. The unit lasts 18 lessons each of 1.5 hours.

The teacher invites the students to perform experiments using all available material. He gives no instructions either about how to use the material or about the physical description. Without telling anything, the teacher demonstrates how to charge a PVC-film and how to detect the charge by means of a neon-bulb. Regarding the students' pre-knowledge about electrostatics we can state that there are only a few elements of experience like getting a stroke at a door or a car. This was one result of our pre-interviews. Thus, the teacher's experiments at the beginning are the only guideline for the students to organize their activities regarding the first situations.

The examples are presented as the description of a student's activities and not as a transcription of the video-recording. Without regarding the video-recordings in parallel, a transcription is very hard to understand.

First example: During the first lesson the students try to charge and discharge several things of their environment. John, one student of the observed working group, tries to charge an aluminum plate. The following ideas are to be seen as organizing elements of the sequence:

Table 1: Relevant cognitive structures of the situation

Principle 1: (Fundamental for the whole sequence) Charge can be wiped off by means of a cloth.

Principle 2: Decisive for a charge phenomenon is the diversion of charges.

Principle 3: It is one character of isolators that charge cannot be moved on the surface.

Aim of the sequence (first order aim):

Two aluminum plates can be charged oppositely by wiping charges from one plate to the other.

Higher aim (second order aim):

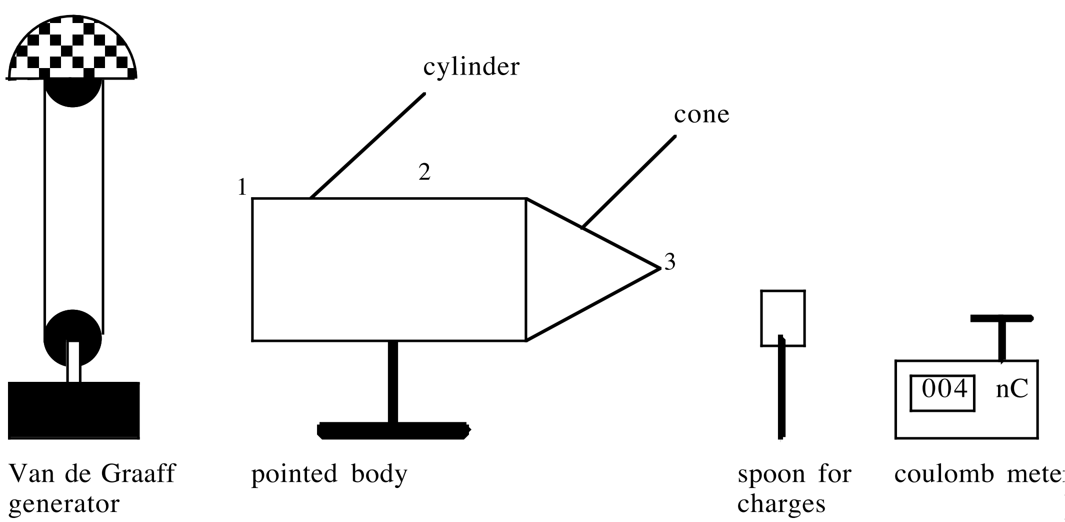
An experiment with two oppositely charged plates and a swinging ball in between can be realized.

Strategy:

John has an idea about an experiment and performs it without being irritated by objections of the other students in the group.

The strategy and the second order aim are part of the context dependent system of reference and the principles belong to the organizer units. Organizer conditions are inherent elements of the first order aim. The first principle is an inadequate principle. Regarding the first order aim, it is not able to organize John's activity adequately. But in spite of an unsuccessful attempt of charging the two plates there is no need to call principle 1 into question. The second order aim, in combination with the strategy, is starting point for another experiment. The only change of John's cognitive part system occurs in differentiating the possibilities of charging two aluminum plates oppositely. The above used method does not work and maybe principle 1 becomes a little bit weaker. In a couple of following sequences it is still an organizing principle for other activities and, as a consequence, basis for many new principles. In an interview after the unit, after having heard a lot about an adequate physical model of charge, John feels still unsure. The interviewer wants him to explain the mechanisms of charging by contact. After having rubbed a ruler with a cloth John says: " We are wiping the electrons to the cloth. we don't know how it works exactly. Some of the electrons go to the cloth or the other way around. Therefore both (the ruler and the cloth) are charged. It happens by pressing without rubbing and always in one direction. In this context there is no difference between lifting off, rubbing, wiping off and lifting down." The old principle does not exist any more and a new one is in sight. It is established without using the physical word "desorption energy". A "misconception" has changed and it is a little bit closer to an adequate physical description. Meanwhile it has done a lot of important organizing work.

Second example: In the sixth and seventh lesson students investigate charged bodies regarding given aspects. To make statements about the distribution of the charge density on the surface of a non-regular object, the observed group performs the following experiment:



Picture 2:

A pointed body will be charged by means of a Van de Graaff generator. Dependent on the curve of the surface more or less charge can be taken off with the spoon and then be indicated with the coulomb meter. The pointed body, the spoon and the plate of the coulomb meter are made out of metal.

The complete sequence is dominated by John. He wants to solve the problem by charging the body and then touching the plate of the coulomb meter with different places of the surface (marked in picture 2 as 1, 2 and 3). Result is that the coulomb meter always indicates nearly the same values because the body is always totally discharged. The following cognitive elements are to be seen as the basic organizers of his interaction during the sequence:

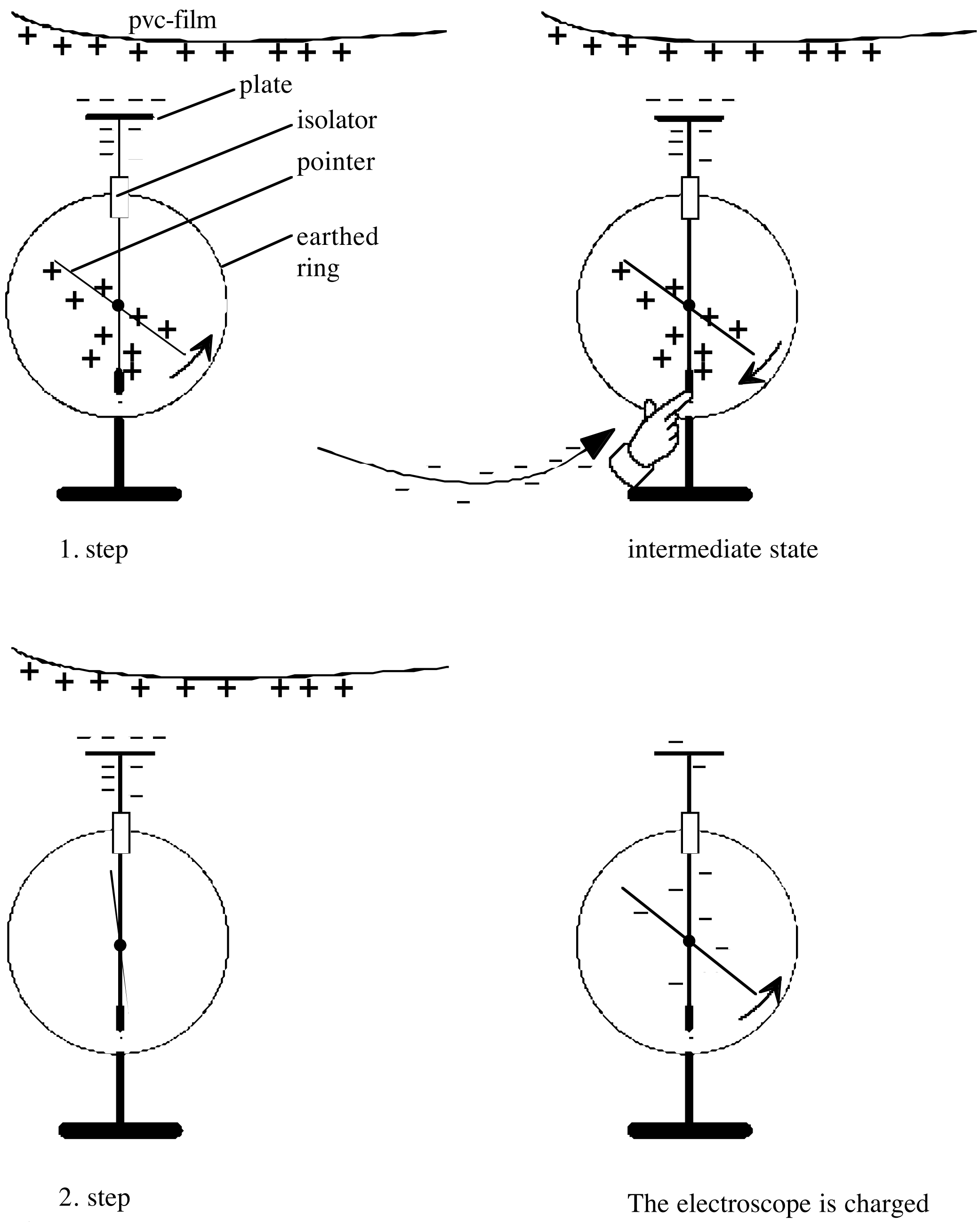
Table 2: Comparison between relevant cognitive structures two situations

<table>
<tr><th>Lesson 6:</th><th>Lesson 7:</th></tr>
<tr><td colspan="2">Principle 1: To find a relation between the different measurements the charge of the pointed body must be reproduced.</td></tr>
<tr><td colspan="2">Principle 2: The same number of turns at the Van de Graaff generator causes the same amount of charge.</td></tr>
<tr><td></td><td>Principle 3: The direct technology of measuring the charge always leads to the body's total amount of charge.</td></tr>
<tr><td>Principle 3: (not explicitely used) It depends on the shape of the surface how much charge goes to the coulomb meter .</td><td>Principle 4: It depends on the shape of the surface how much charge goes to the spoon.</td></tr>
<tr><td colspan="2">First order aim: The charge density at several places of the surface of a pointed body shall be indicated.</td></tr>
<tr><td colspan="2">Second order aim: The problems that teachers give have to be solved.</td></tr>
<tr><td>Strategy: The body has to be charged and the coulomb meter has to touch the surface at different places.</td><td>Strategy: The body has to be charged and the surface must be touched by the spoon at different places.</td></tr>
</table>

At the beginning of the seventh lesson the group continues experimenting. Now John, still the dominating person of the group, uses the spoon to discharge the body and he succeeds. His interpretation of the measurement: The more the place is bended where the spoon touches the more charge is taken off. The implicit result of the sixth lesson that it doesn't work this way is basis for the activity of the seventh lesson. For John the "misconception" of lesson 6 was necessary to differentiate this principle about charge distribution.

Third example: The next example belongs to an electrostatic unit in grade 10 of a highschool. It is an example of an "imaginary" misconception. Aim of the unit was to establish an idea about voltage. The unit includes 16 lessons of 1.5 hours each. The students are working together in groups of 4. Two students named Careen and Jessica try to charge an electroscope by influence. Before the group starts experimenting in the fourth lesson Careen explains that, as a consequence of attraction between different charges, negative charges move towards the plate and the pointer and its suspension are charged positively, when a positive charged PVC-film is held above the electroscope. To keep the electroscope charged she explains that the pointer must get earthed to allow negative charges to neutralize the positive charges of the electroscope. This was an adequate explanation of the underlying physical model on what we call a principle-level of complexity. Careen is not interested in performing the experiment but after some discussion in the group she explains how to do it. This explanation does not contain any of the above outlined physical models. It contains a sequence of action on a program-level to succeed in charging the electroscope.

Jessica, a girl in the same working group, tries to comprehend Careen's instruction by performing the experiment. She has no ideas about a physical model and makes no efforts to comprehend it. In the first step she touches the plate of the electroscope with a (positively) charged PVC-film. As a consequence of a discussion in the working group about how to charge an electroscope by influence, Careen modifies the first step. Thus, the PVC-film is held above the plate without touching it (picture 1). As an intermediate state the pointer and the suspension get earthed and negative charges from earth neutralize the positive charges of the electroscope. Jessicas activities differ from the sequence shown in picture 1. Jessica removes her earthing hand after removing the PVC-film and the electroscope is discharged at the end.



Picture 3:
How to charge an electroscope by influence. The plate, the pointer and the ring are made out of metal. The plate and the pointer are connected conductingly.

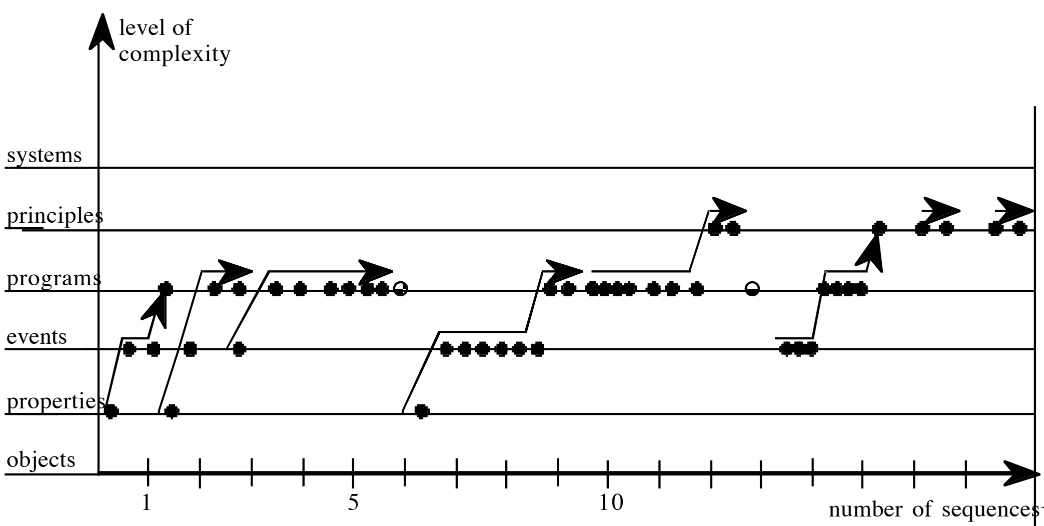
Correctly, as shown in the picture, the hand has to be removed in the second step. Then the electroscope contains a surplus of negative charges. After removing the PVC-film the negative charges spread all over the connected parts of the electroscope and the pointer indicates charge, again.

After a longer period of unsuccessful experimenting, a student of another working group explains the proper order and Jessica succeeds. In the sixth lesson Jessica tries to charge an aluminum foil by influence and again she mixes the order of activities. Careen points out the mistake and after some explanations on the program level Jessica succeeds again. Jessica has no concept to explain what's going on in the electroscope and that is the reason of her difficulties. She has to remember the correct order of activities to succeed and no possibility to reconstruct it. Any concept about charges would help her to plan the own action and would give the teacher and other students a chance to discuss conceptual problems. A very interesting social component of the situation is the effect that Careen not only points out the mistake of Jessica but also the level of her cognitive efforts. In lesson 4 Careen first explained her model of charge moving and forces on a principle level. The second explanation and all others of this lesson and of lesson 6 regarding influence only contains an action program to put the single activities in order. This was the level of complexity of Jessica's cognitive organisation of action.

Conclusions

Our statement at the beginning was: Models based on the hypothesis of "misconceptions" are not viable to understand students' learning processes. We will give an example how differentiated a learning process can get modelled and which conclusions we can draw out of it.

Manuela Welzel, one of my co-workers, has shown how a student's complexity of meaning develops in the course of time. Let us give you an example:



Picture 4:

It is shown how the complexity of a student's cognitive constructions related to "charging an aluminum-film" develops in a period of 15 minutes of interactions. The filled spots mark those ideas which belong to a closed sequence of activities. The other spots are single ideas with no remarkable connection to others.

As mentioned, the content of the graph of picture 4 relates to "charging an aluminum-film" but that is not important. The main point is that probably not one of these ideas has the complexity an expert's idea would have in the same situation. Thus every idea might be inadequate from a physicist's point of view but if we have a look at the complete development, every idea is necessary for the student to come to a higher complexity level and maybe, at the end of 26 lessons about electrostatics, in some situations the student is able to organize her action like a physicist would do (Fischer et al. 1992).

Let us end with an example. Younger students prefer a consumption concept to describe what is going on in a simple electric circuit. Modern teachers have heard about it during their own studies and they are prepared to answer. When the young student grows older it seems that he has nothing heard about conversion and flow of energy and even at the universities we sometimes find inadequate ideas about electricity and current. To state that there are conservative "misconceptions" helps to describe the situation but it does not help to learn about the students' learning abilities and to describe their learning pathways. There is no need for a teacher to know which "misconceptions" are possible but he has to know how to organize instruction in a way that recent ideas of a student become available. Teachers must learn how to prepare the learning environment for students' communication and self-determined activities and then to listen. If he is a well prepared physicist, he must not know that a student might use a current consumption idea. As a physicist he knows that current consumption is not an adequate model to describe electric circuits. As a very reserved partner of communication he has to find out on which level of complexity the student constructs his ideas and how to give new stimulations to invite the student developing new ideas.

In one of our projects at the Institute for Physics Education in Bremen we try to find out which higher order cognitive structures, we call it orienting elements of cognitive systems (OECS), like epistemological frameworks, intentions, physical views or attitudes are responsible for the character of context dependent activated cognitive structures. Those context dependent structures which depend on short term cognitive development we call:

context dependent cognitive system (CDCS). Both, OECS and CDCS are determining the student's recent perception, aim and expectation in a situation including problem solving abilities and knowledge activation.

To talk about "misconceptions" obscures the view of the problem to find out which dominating cognitive structures are the reason for difficulties most students have with learning physics.

References:

Bauersfeld, H. (1983). Subjektive Erfahrungsbereiche als Grundlage einer Interaktionstheorie des Mathematiklernens und -lehrens. In *Untersuchungen zum Mathematikunterricht*. Köln: Aulis Verlag.

Fischer, H. E. (1993). Framework for Conducting Empirical Observations of Learning Processes. *Science Education* 77 (2): 131-151.

Fischer, H. E. & Aufschnaiter, St. v. (1991). The increase of complexity as an order generating principle of learning processes. Case studies during physics instruction. In R. Duit, F. Goldberg & H. Niedderer (Eds.), *Proceedings of the "Bremen International Workshop: Research in Physics Learning and Empirical Studies"*, March 1991. Kiel: IPN.

Fischer, H. E. & Aufschnaiter, St. v. (1993). Development of Meaning During Physics Instruction: Case Studies in View of the Paradigm of Constructivism. Science Education 77 (2) 153-168.

Glasersfeld, E.v. (1989). Cognition, construction of knowledge and teaching. *Synthese*, Vol. 80, Dordrecht, 121-140.

Lawler, W. (1980): The progressive construction of mind. *Cognitive Science* 5, 1980, 1-30.

Piaget, J. & Inhelder, B. (1969). *Die Entwicklung der physikalischen Mengenbegriffe beim Kinde*. Stuttgart: Klett-Cotta.

Piaget, J. (1926). *La représentation du monde chez l'enfant*. Paris: Presses Universitaires de France.

Piaget, J. (1974). *Der Aufbau der Wirklichkeit beim Kinde*. Stuttgart: Klett-Cotta.

Piaget, J. (1978). *Das Weltbild des Kindes*. Stuttgart: Klett-Cotta.