

# **Learning process studies in physics: A review of concepts and results**

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## **Abstract**

Investigations about changes of conceptions during physics instruction are seen as the logical and necessary next step to follow the successful international research on students' pre-instructional conceptions. The paper analyses theoretical issues related to the terms "learning processes" and "cognitive system". It starts with a differentiation of "conceptual change" towards learning as formation of new additional cognitive structures vs learning as change of qualities of structures being already there. Such qualities can be "strength" and "status" of a conception as well as the "level of explanation". The paper is oriented towards explicit cognitive descriptions related to specific contents of physics. It reviews selected content specific results and comes to general hypotheses about learning. It also shows examples of "learning pathways" defined by "intermediate conceptions", seen as a result of self development of the cognitive system of students. As a result, a different view on the final state of the cognitive system after teaching is proposed. Learning processes as construction of new cognitive states by using cognitive tools are analysed.

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# **Learning process studies in physics: A review of concepts and results**

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## **1. Why content related research on learning processes?**

The following paper will analyze empirical learning studies in physics instruction. My special interest are empirical studies continuously recording learning processes in real class room instruction and aiming at analyzing the results in view of the change of cognitive structures. In addition, I consulted studies describing in some detail the final cognitive state after a learning process.

An increasing number of researchers in physics education turning to a constructivist paradigm, such learning process studies appear to be an objective of some significance. If you follow von Aufschnaiter (1991) that learning is a self development of a cognitive system, learning process analyses having a cognitive approach are obligatory. In addition to the content orientation of the learning offers (teacher, media, written texts etc.) the analysis of the effects of learning environments (particularly of students' activities) on the students' actual learning process should be focused. An appropriate modeling in view of content related purposes of students' cognitive systems appears inevitable in this context in order to make possible a clear distinction of the students' learning processes as compared to the process intended by the teacher. Thus, evidence of students' learning processes not intended by the teacher is of specific interest (e.g. Niedderer & Goldberg, 1995).

A further aspect is favoring a content related research field "learning process analysis". The most successful field of research in the past twenty years in physics education has been the investigation of students' conceptions shown on world wide conferences and bibliographies (Pfundt & Duit, 1994; Carmichael et al., 1990). From the cognitive point of view the research results are descriptions of cognitive states, mostly before teaching, sometimes after teaching. To be able to judge, however, learning effects of curricula, media, certain types of instruction, and teacher approach the change of such cognitive states in the course of instruction and the processes involved have to be investigated. Probably also for teachers appropriate cognitive models are of importance for a better understanding of their own action. Von Glasersfeld (1992) says in this respect: "... in order to teach one must construct models of those "others" who happen to be the students." A further step in research development relating to "students' conceptions", aiming at the description of temporal processes of change of such students' conceptions appears to be the need of the hour. This was also the purpose of an international workshop held in Bremen in 1991 (see Duit, Goldberg & Niedderer, 1992).

At the moment, in Bremen three research teams (v. Aufschnaiter, Niedderer and Schwedes) are working on the subject of learning process studies in physics instruction. Common to all of them is the concentration on studies during instruction, using qualitative case studies with individual students of different age groups in real instruction contexts. The teams are working, however, on a partly different theoretical basis. In the team von Aufschnaiter learning is mainly analyzed and described as

development of complexity under rather structural aspects. In the team Niedderer, content related modification of cognitive elements such as alternative frameworks, conceptions, schema etc. are used to describe learning. In the team Schwedes further development of the "conceptual change" approach together with analogies form the most important theoretical basis.

## **2. Comments on a theoretical frame used in content related investigations**

### **2.1 Description of the cognitive system in physics learning**

Description of content related parts of the cognitive system in physics learning has been carried out in the two following ways:

- *Propositional knowledge.* In this method terms (conceptions) are chosen and subsequently statements are formulated which can be supposed to be student's "mini theories" and thus can serve to explain his behavior in speaking and acting. This area comprises (students') ideas and mental models.
- *Description of concept maps or conceptual maps.* This method shows in graphs the most significant terms and their interrelations which are supposed to have a behavior generating structure for the student.

The display of cognitive structures in the form of "ideas", "pre-concepts", "conceptual structure" or "conceptions" and their relations seems to be important, perhaps even indispensable for didactic issues. This raises, however, the following problem: does the assumption of representation of such content related cognitive structures possibly prevent to realise more general production systems within the cognitive system which might explain the constructions and learning processes observed in a simpler and more general way? In our<sup>1</sup> opinion such production systems or tools might still have a considerable explanatory potential, up to now only partly disclosed for the area of schema. For studies in physics education, however, the following attitude seems to me specifically fruitful until a satisfactory evidence of such more general production systems is given: We handle content descriptions of cognitive systems (e.g. as "conceptions") as if they were stored in mind (representation of knowledge), knowing that this is only a comfortable type of presentation which will have to be replaced later by description of more general production systems or "generating structures" of the cognitive system with declarative and procedural parts.<sup>2</sup> Thus, conceptions are content related characterisations of especially frequent or probable actual constructions of students.

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<sup>1</sup> "our" in this context means my construction of consenses from the discussion in the Institute of Physics Education at the University of Bremen.

<sup>2</sup> The "cognitive tools for knowledge construction" noted in Niedderer & Goldberg (1995) include as essential elements also schema and other linguistic basic elements and seem to be very close to such "production systems".

## 2.2 Basic terms "learning" and "learning process"

From the papers mainly of the Bremen working groups in the past few years it appears necessary to describe learning processes on different levels: as students' current construction processes during instruction which in the long run may, but not necessarily, lead to learning; as "learning pathways" with virtually stable intermediate states in the learning process, as modification of characteristics of such cognitive structures, and finally as effective cognitive construction processes causing transition from one cognitive state to the next. These meanings are compared in the following diagram:

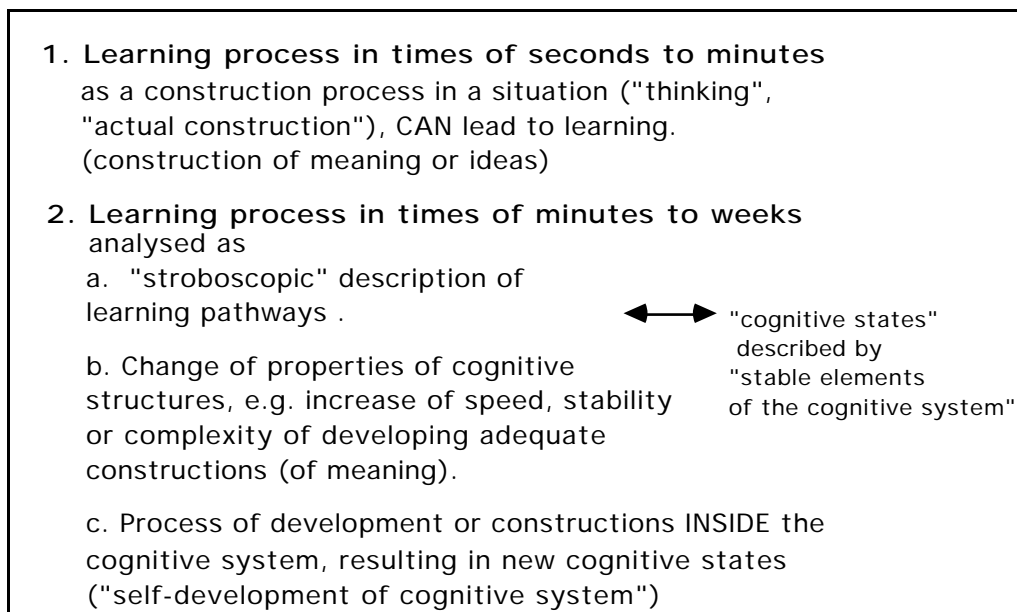


Fig. 1: Different meanings of learning

The distinction of current constructions and stable cognitive elements is also emphasised in the model of a content relevant description of the cognitive system proposed by Niedderer and Schecker (see Fig. 2). This model stresses the following aspects:

- learning is to be seen as a change of stable elements of the cognitive system
- any actual construction is determined by stable elements of the cognitive system and the context of the situation ("situated cognition")
- a first task in analyzing learning processes is to determine changes of stable elements, to give evidence for some stability of a change

As is shown from the results of various empirical studies in physics instruction, learning is described on the one hand as development of new cognitive structures and, on the other hand, as modification of certain characteristics of these structures (see Fig. 3).

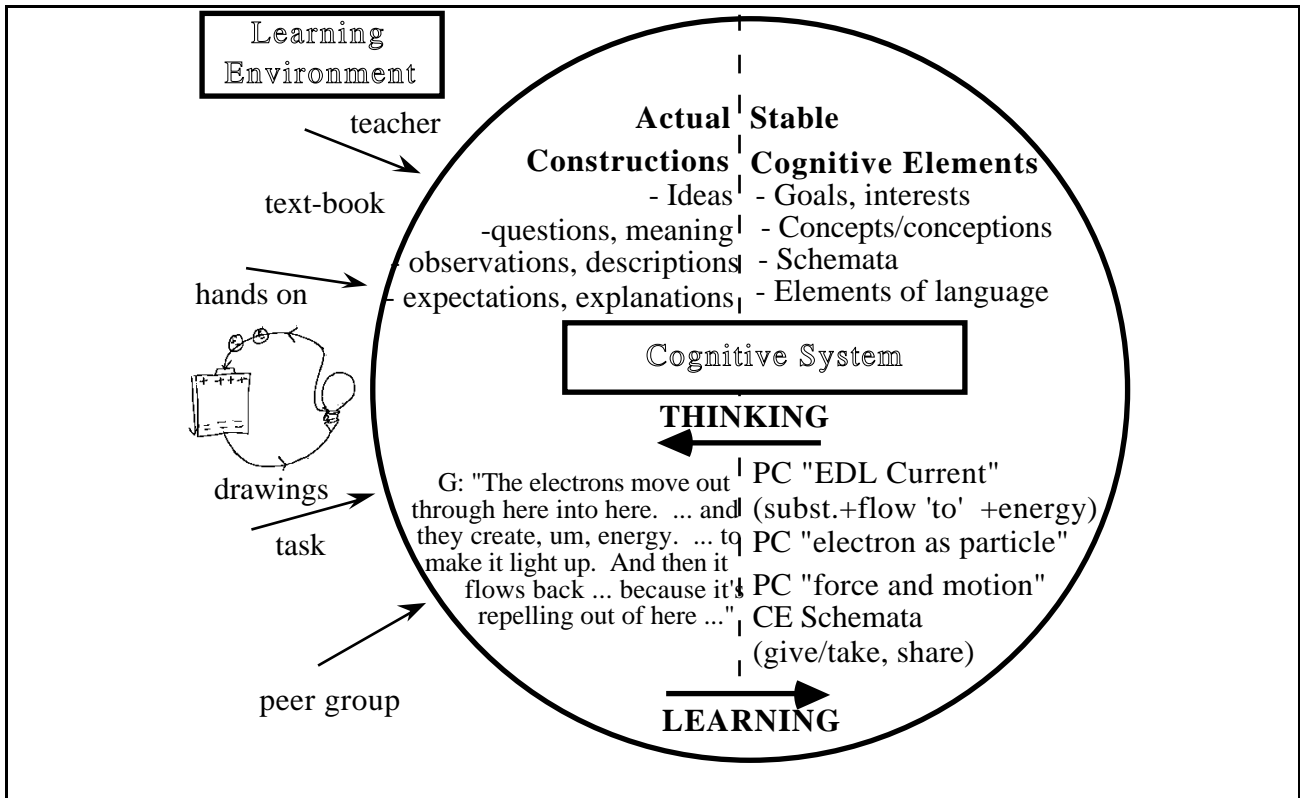


Fig. 2: A model of the cognitive system (Niedderer & Schecker, 1992, 84)

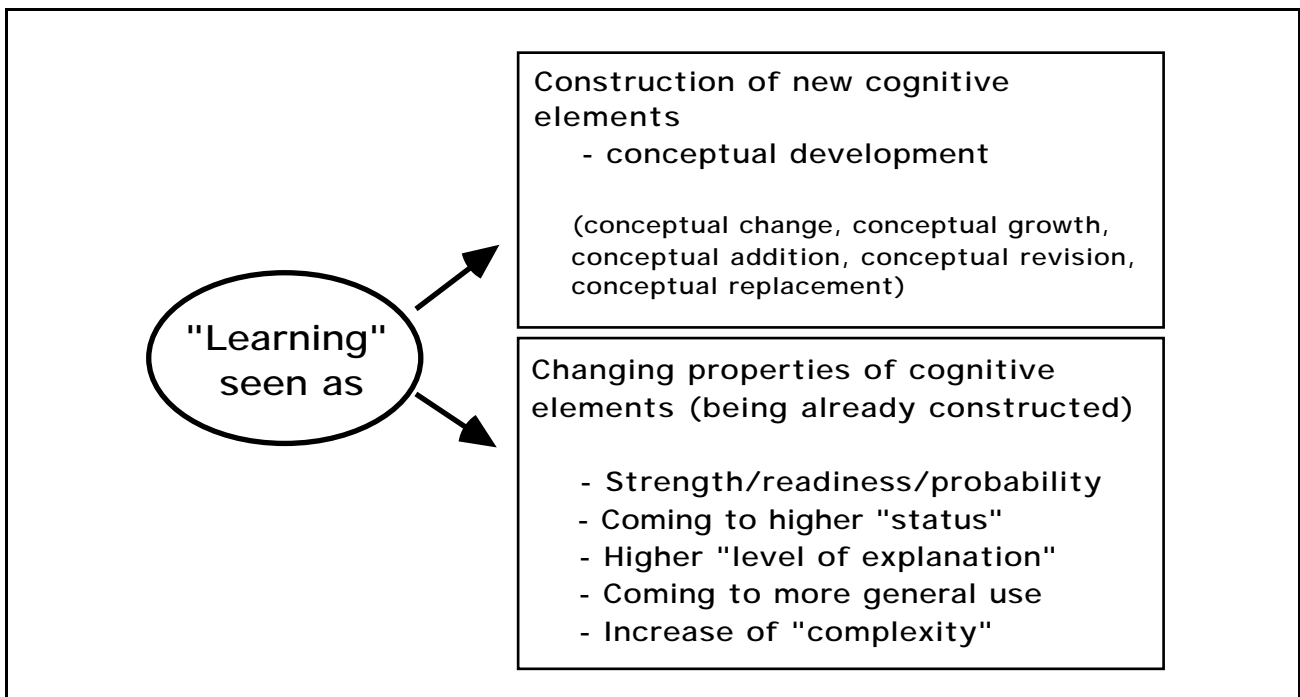


Fig. 3: Two ways of learning

In the first case, we have a long tradition of empirical and theoretical research using the term "conceptual change". In the course of this research the originally existing idea of replacing false ideas (misconceptions) by correct conceptions has been replaced by the notion, that the learning process is a development of parallel cognitive structures (conceptual addition, conceptual growth, conceptual development) (Duit 1997). There exist already numerous research results on the second way of learning as shown in this paper.

### 2.3 Content related description of learning processes - an example

In the following example a learning pathway is described as a sequence of cognitive states, each state characterised by a conceptual map (fig. 4):

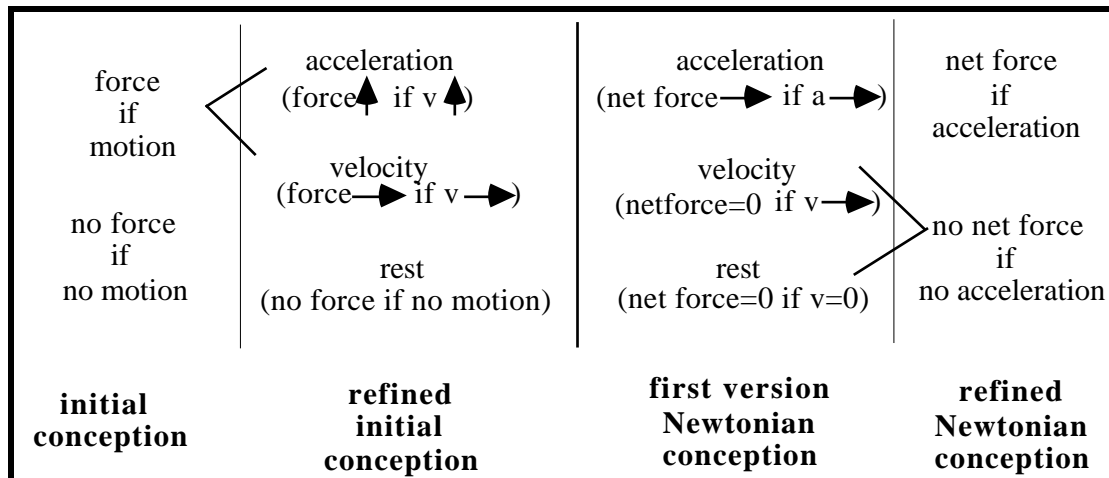


Fig. 4: A series of conceptual maps (Dykstra, Boyle & Monarch, 1992, p. 627)

The figure shows a description of four cognitive states as "initial conception", "refined initial conception", "initial Newtonian conception", and "refined Newtonian conception". These four states are described by key conceptions and their interrelations (arrows) partly showing modified meanings. If, for example, the first state includes an arrow "force causes motion" and the third as well as the fourth state an arrow "net force causes acceleration" this modification also means a change of the concept force: in the first case force is essentially characterised as cause of all motion while in the second case the resulting force is only relevant for generation of acceleration.

## 3. Empirical design of the studies

### Continuous data collection during instruction

As already noted my main interest is for such empirical studies using continuous data collection during instruction as main data basis. On the whole sixteen empirical studies of this type have become known to me in the field of physics instruction (Scott, 1987; Brown, 1987; Brace, 1988; Fischer, 1989; Schmidt, 1989; Lichtfeldt, 1992; Roschelle, 1991; Lewis, 1991; Katu, 1992; Tytler, 1994; Welzel, 1994; Seibel, 1995; Komorek & Duit, 1995; Wodzinski, 1995; Niedderer & Goldberg, 1995; Petri, 1996). Most of these studies are published as doctoral dissertations. Six of them come from the three Bremen research groups. The main data basis are audio and video records of normal classroom instruction subsequently transcribed. In their following interpretive analysis the Bremen studies differ from all others in their much more detailed manner to record, analyze, and model the cognitive processes of individual students.

## **Recording of intermediate states by interviews**

Interviews in certain intervals in the course of the instructional process are a further important method mostly applied in addition to the continuous data collection (Scott, 1987; Brown, 1987; Lewis, 1991; Hammer, 1991; Lichtfeldt, 1992).

## **Cognitive analysis of the final state**

In physics education there are numerous papers describing the success of learning quantitatively by differences of scores between pre-instructional and post-instructional tests and comparing them with other instruction methods. In some cases, a sort of cognitive analysis of the final state achieved is attempted. Such an analysis of empirical results appears to be a valuable contribution to the analysis of learning processes. As one example for such investigations I only refer to the study of Galili, Bendall & Goldberg (1993).

## **4. Examples of results**

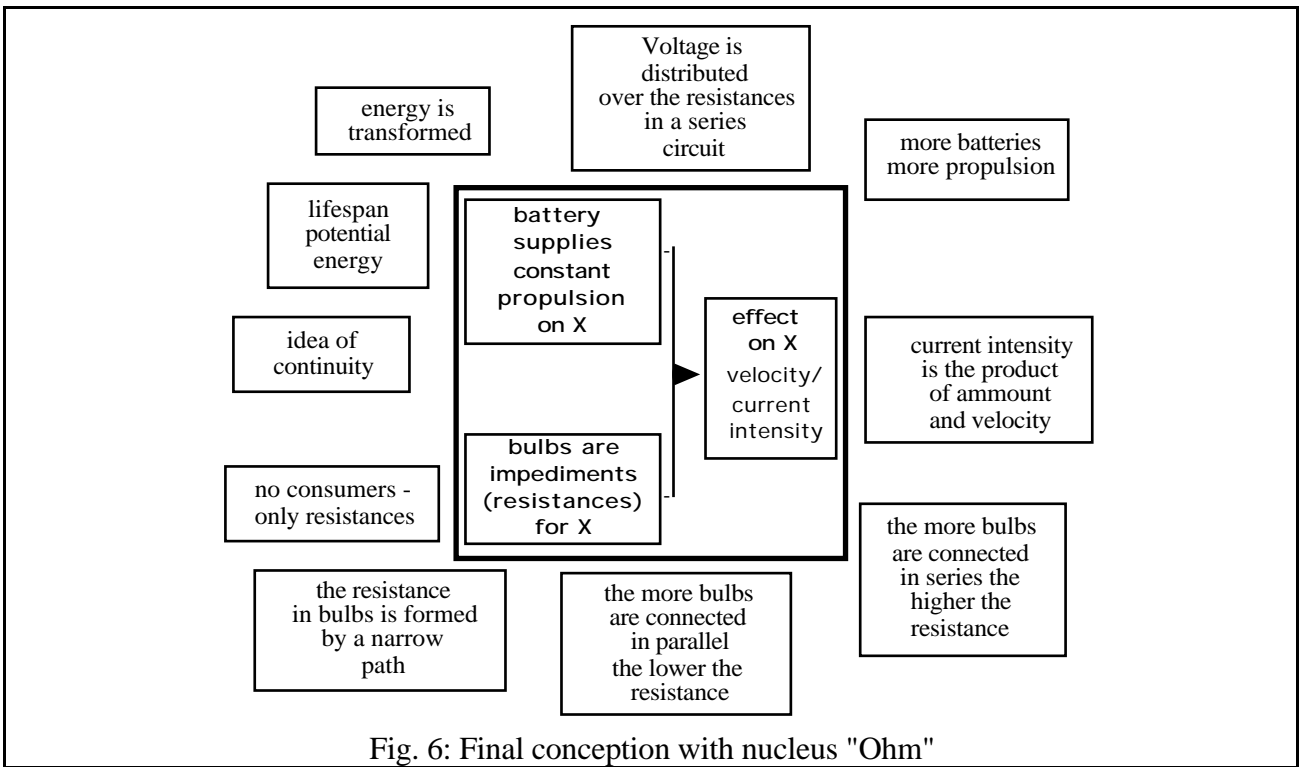
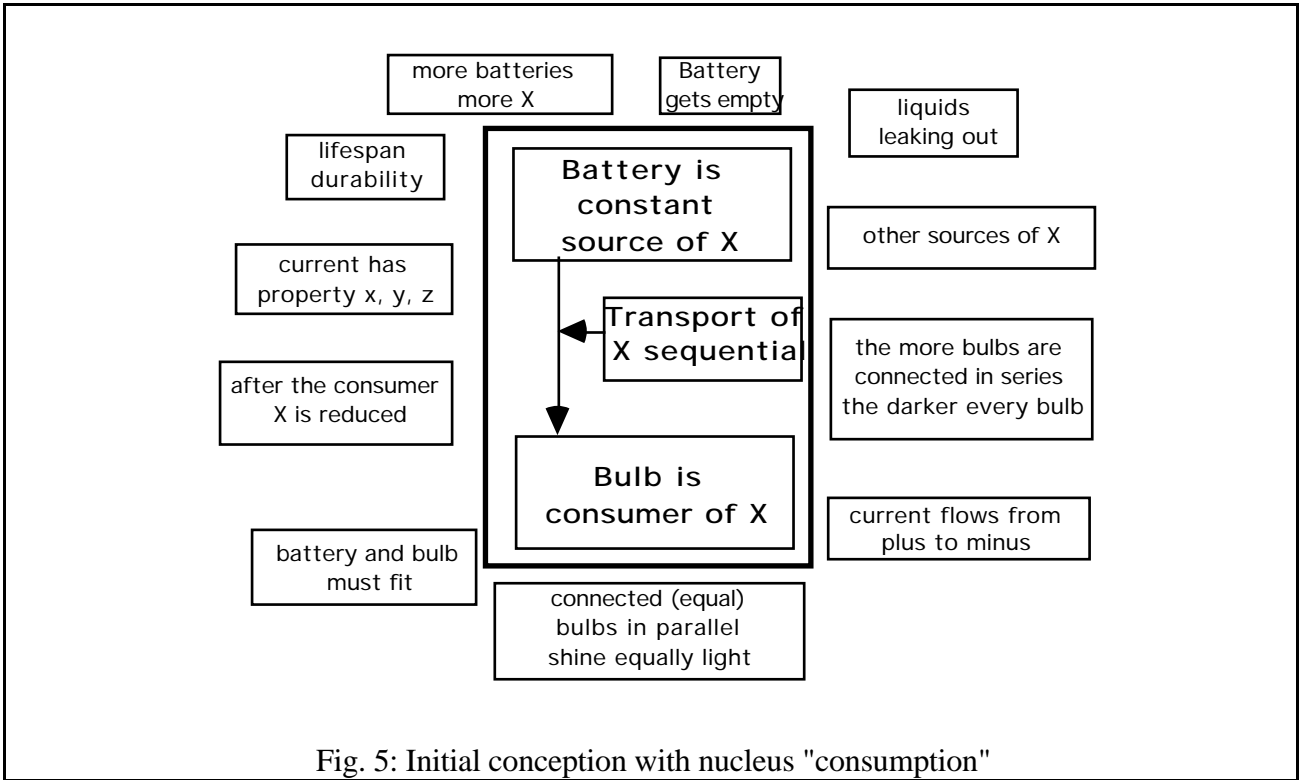
### **4.1 Learning as development of new cognitive structures**

#### Description of cognitive structures relevant for didactics

A significant partial result of all those studies is a cognitive description of knowledge structures relevant for didactics. As far as content related descriptions are concerned, these can almost always be categorised somewhere between pre-instructional everyday conceptions and scientific conceptions as "intermediate conceptions". Physics learning thus appears as a process in which instruction incites the self development of the cognitive system and leads to intermediate states. These intermediate states have to be regarded as developmental steps on the pathway to a scientific view. They are perhaps determined both by the state of the cognitive system before instruction with its potential of development and by the specific concept of instruction.

#### Conceptual change

One of the first learning process studies in physics known to me (Schmidt, 1989; Schwedes & Schmidt, 1992) shows, in accordance with the then prevailing theory of conceptual change, a change from an initial conception "consumption" to a final conception "Ohm". Of specific interest in this study is the description of a cognitive state as "conception" by means of a "nucleus" and specific propositional sentences referring to different single situations.





The nucleus is regarded as the behavior organizing structuring element, producing further specific views in interaction with specific situations. From today's view one would perhaps characterise the final state achieved by the fact that it represents the initial conception as well as the final conception (and possibly even others) with different powers and different status.



Layers in the final cognitive state

The aspect of the simultaneous existence of different cognitive structures in the final state achieved after teaching has been described for the first time and very impressively in the work of Scott (1987, 1992). He investigates in his "pathways in learning science" one student Sharon during instruction aiming at a particle conception of solids, liquids, and gases.

Fig. 7: A closed flask containing air	Fig. 8: A closed flask after some air has been taken out
	
<p style="text-align: center;">Sharon's drawing Before                      After teaching</p>	<p style="text-align: center;">Sharon's drawing Before                      After teaching</p>

(Scott 1987, 1992; see also Novick&Nussbaum 1981)

At the end of the unit she appears to dispose of both conceptions (gas as a continuous substance and gas as an accumulation of small particles) and is able to distinguish between them. In everyday life (e.g. when talking to her mother) she would apply the old, continuous conception, however, discussing with her teacher she would make use of the new conception in various explanations (Scott, 1992, p. 222). In a similar way, Niedderer & Goldberg (1992, p. 15-18), during their analysis of an action sequence at the end of an instruction unit, find that students recur to different "layers" of their cognitive system in the course of their 20 minutes discussion on the explanation of a new experiment. These layers comprise, among others, the initial conception, an intermediate conception and parts of the scientific conception aimed at. Niedderer&Petri show the same structure of the final state in their analysis of a learning process in quantum atomic physics (Petri 1996; Niedderer&Petri 1997). They see the final conception of an atom as a federation of the planetary model, the quantum model and the smeared electron cloud model, each of them with different values of status and strength.

Achievement of cognitive states not intended

A further important general result of learning studies in physics is the evidence that students achieve cognitive states not intended by the teacher which, normally, are between the initial conceptions and scientific theory. One example for such process is given in the study of Galili, Bendall & Goldberg (1993) in the field of optics.

In addition of the description of this conception by iconical representations (see Fig.9), the authors use also verbal propositional descriptions of the "core concepts" and the "main ideas". They call the particularly interesting intermediate state achieved after instruction as a result of physics learning the "relevant ray conception". It is characterised by the fact that only a selection of relevant rays are used for image construction, consequently leading in some situations to characteristic mistakes, while the scientific image construction takes in consideration all light rays emanating from an object. The

authors call the knowledge achieved at the end of the instruction as "hybrid knowledge" characterising an "intermediate state".

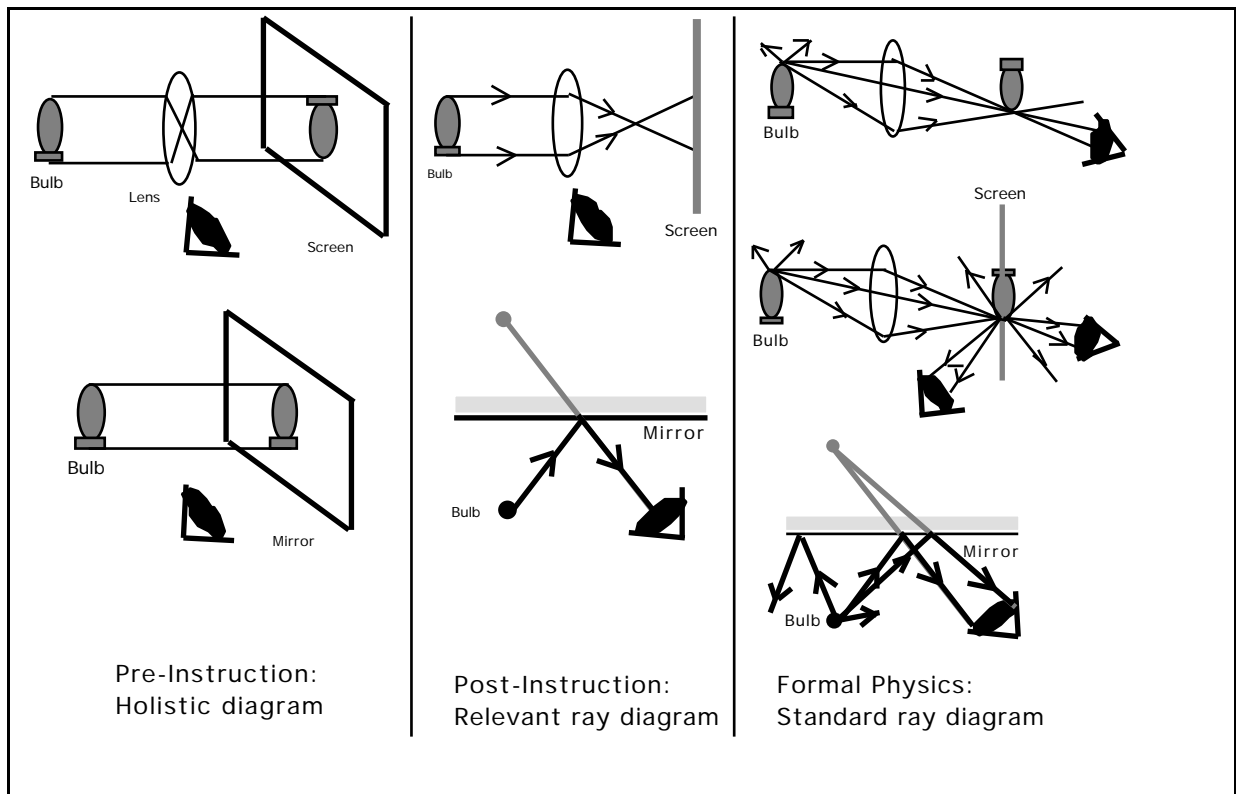


Fig. 9: Optical image construction by rays. Comparison of conceptions before and after instruction with the physical concept. According to Galili, Bendall & Goldberg (1993, p. 296)

Such intermediate states achieved by students of different age groups during the learning process are described as well by Niedderer & Goldberg (1995) for electric circuits, by Lewis (1991) for thermodynamics, and by Dykstra (Dykstra, 1992; Dykstra et al., 1992) relating to the mechanical concept of force. In connection with the idea of self development of the cognitive system I formulate a general hypothesis: There are significant content related intermediate conceptions frequently developed by students of different age groups in physics learning independent of the particular teaching concept. They could be denominated as "attractors of the cognitive development".

### Describing learning pathways

Some studies come to describe learning pathways by means of intermediate states achieved. Already Scott (1987, 1992) uses the term "conceptual pathway" to describe such a learning pathway. More explicitly such learning pathways are described by Lewis (1991), Lichtfeldt (1992), Niedderer & Goldberg (1995), and Petri (1996).

Lewis (1991) starts with listing five "target scientific conceptions" in a table (table 2, p. 46-48): thermal equilibrium, conduction, insulation, heat energy, and temperature. She compares these scientific conceptions to several "intermediate conceptions" and "misleading intuitive conceptions". The learning process is subdivided in relation to each of these five target conceptions as the pathway leading from the "intuitive conception" to the "target conception" via five "levels of explanation". This process is shown for individual students (see the bottom of fig. 17). The intermediate steps are

indicated as "encoding new facts without explanations", "mixed predictions, idiosyncratic explanations", "mixed predictions, explanations", and "good predictions, mixed explanations". This description of learning process thus is a mixture of qualitative description of the changes from "intuitive conceptions" via "intermediate conceptions" to "target conceptions" with a quantitative description via the level of explanation.

Lichtfeldt (1992) uses so-called networks of ideas to show cognitive states. In particular, he describes in detail the learning pathway of a student in the domain of quantum physics as a dynamic development (change) of networks of ideas including eleven stations each represented by such a network of ideas. In the networks of ideas the crucial terms of the initial conceptions as well as of the target conceptions are included, and the marked relations are gained by analysing transcripts from instruction or from interviews, respectively. The learning pathway is shown as a step by step development of the networks over many stations and on the whole shows a process of increasing links by new relations between the conceptions disclosing also the weight of a particle oriented description of electrons to a description of the electrons as quantum objects, and thus a qualitative change of the conceptions. (Individual case study of one student, Lichtfeldt 1992, p. 295-353).

Niedderer & Goldberg (1995) show the learning pathway in the course of two double lessons by a sequence of four cognitive states characterised by the relevant conceptions. Each of these conceptions is described by core statements and complementary statements as well as by iconic representations.

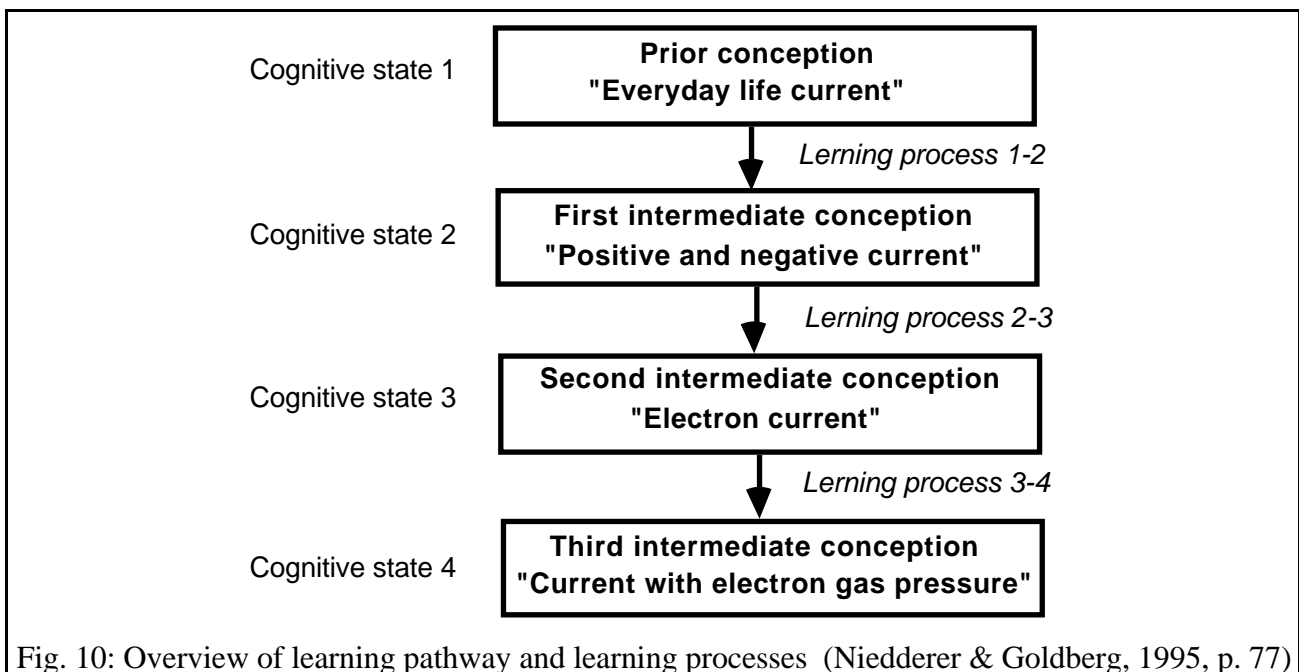


Fig. 10: Overview of learning pathway and learning processes (Niedderer & Goldberg, 1995, p. 77)

As an example the description of the initial conception "everyday current conception":


<p>The prior conception "<b>EDL-current</b>":          Current is seen as a substance, containing energy like fuel. Special facets:          - "electricity": substance like fuel, energy          - current consumption          - "movement" (flow 'to', flow 'through'), and          - from battery through wires to the bulb          This conception is used extensively throughout the whole process giving its meaning to the words "current" and "pressure". That means that these concepts get a bias which relates them directly to effects like brightness of bulbs, number of bulbs and batteries, no matter whether there is a parallel or series circuit.</p>	 <p style="text-align: center;"><b>"current"</b> <b>like fuel</b></p>
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Fig. 11: Initial "everyday current conception" (Niedderer & Goldberg, 1995, p. 77)

Supplementary to the description of learning pathways by cognitive states they attempt to reconstruct also the learning processes as processes of modification of the cognitive system as a result of the course of instruction. In this case the analysis of transcripts supplies ideas what cognitive tools - for example everyday conceptions, schema, or elements of colloquial speech - are used to construct those intermediate conceptions. Their analysis of "knowledge construction" pursues two goals:

- to formulate hypotheses on the effects of single teaching elements on the construction of intermediate conceptions, and
- to formulate hypotheses on the cognitive tools used by the students in the learning process.

Examples for such hypothetical cognitive tools used for developing the cognitive intermediate state "electron current" are listed below (see Fig. 12).

<p><b>Hypothetical cognitive tools used for knowledge construction</b>          Students make sense of the teaching input "electron" by using certain cognitive tools like "electron as a particle" or other cognitive tools from everyday life language like to travel, to stay, to push etc., thus constructing their new intermediate conception "microscopic view of electron current".</p> <p><b>Cognitive tools specifically related to electric circuits</b></p> <ul style="list-style-type: none"> <li>• electron as a particle;</li> <li>• charge (positive and negative); electrons are negatively charged; this might lead to repelling (forces) between them and to attracting (forces) from the positive end of the battery</li> </ul> <p><b>Cognitive tools of everyday language</b>          (contributing to knowledge construction of this intermediate conception in a similar way as schema)</p> <ul style="list-style-type: none"> <li>• electrons can move, go up there, not stay there; electrons can travel, they can stop, go back (to the battery); the movement has a unique direction; they can keep going; they flow (in circular motion)</li> <li>• electrons can push other electrons or atoms; they can be pushed; thus electrons make movement of atoms in bulb (which causes light production); and electrons themselves can be moved that way.</li> <li>• number of electrons; the number of electrons can be seen the same moving in and out of bulb or battery (conservation)</li> <li>• electrons need some room to move; nowhere to go means that no movement is possible</li> </ul>
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Fig. 12: Hypothetical cognitive tools for developing the conception "electron current" (Niedderer & Goldberg 1995, p. 81)

The cognitive intermediate state "electron current" is then described as follows:

<p><b>Intermediate conception "electron current" (microscopic view of current)</b></p> <p>Center (nucleus) of this conception: Protons stay, electrons move, in a circular motion, going from battery to bulb in one wire and back in the other (different directions). Motion of electrons makes movement in bulb and produces heat and light. The motion is driven by repelling and attracting forces from the battery. Conservation of number of electrons seems intelligible, but is <u>not</u> seen consistently as a rule, electrons still have the - additional - meaning of "fuel". Amount of current is <u>not</u> seen consistently in relation to speed of electrons.</p>
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Fig. 13: Second intermediate conception "electron current" (Niedderer & Goldberg 1995, p. 81)

## 4.2 Learning as modification of the characteristics of already existing or newly developed cognitive structures

### Learning as a modification of "status"

Hewson & Hennessey (1992) describe the learning process of a girl student on the force conception as a modification of the "status of students' conceptions". The study is dealing with Newton's third law, especially with the example of a book on a table experiencing two forces, that of weight and a counterforce exerted from the table. The authors describe the conception and its status before, during, and after instruction, and six weeks later. The conception changes rather quickly from an everyday conception to a scientific conception the status of which is getting higher in the sense of "intelligibility", "plausibility", and "fruitfulness" in the course of teaching.

### Learning as development of "complexity"

In the last ten years the group von Aufschnaiter in Bremen worked on several research projects on the subject of learning as development of complexity of construction of meaning of individual students in physics learning (Fischer, 1989; Fischer & von Aufschnaiter, 1992; Welzel, 1994). In order to characterise the levels of complexity a taxonomy originally developed by Powers (1973) is used. Welzel (1994) uses the following levels of complexity: the level of objects, the level of characteristics, the level of events, the level of program, and the level of principles. These levels of complexity can partly also be regarded as an increasing level of abstraction. In this sense four of the five levels (level of objects, level of characteristics, level of program, and level of principles) are common also in other relevant physics papers (see Fig.14). The two subsequent figures show the development of complexity of constructions of meaning of an individual student Jessica in instruction sequences of 20 minutes each in similar situations in the 4th and 6th double lesson of the unit:

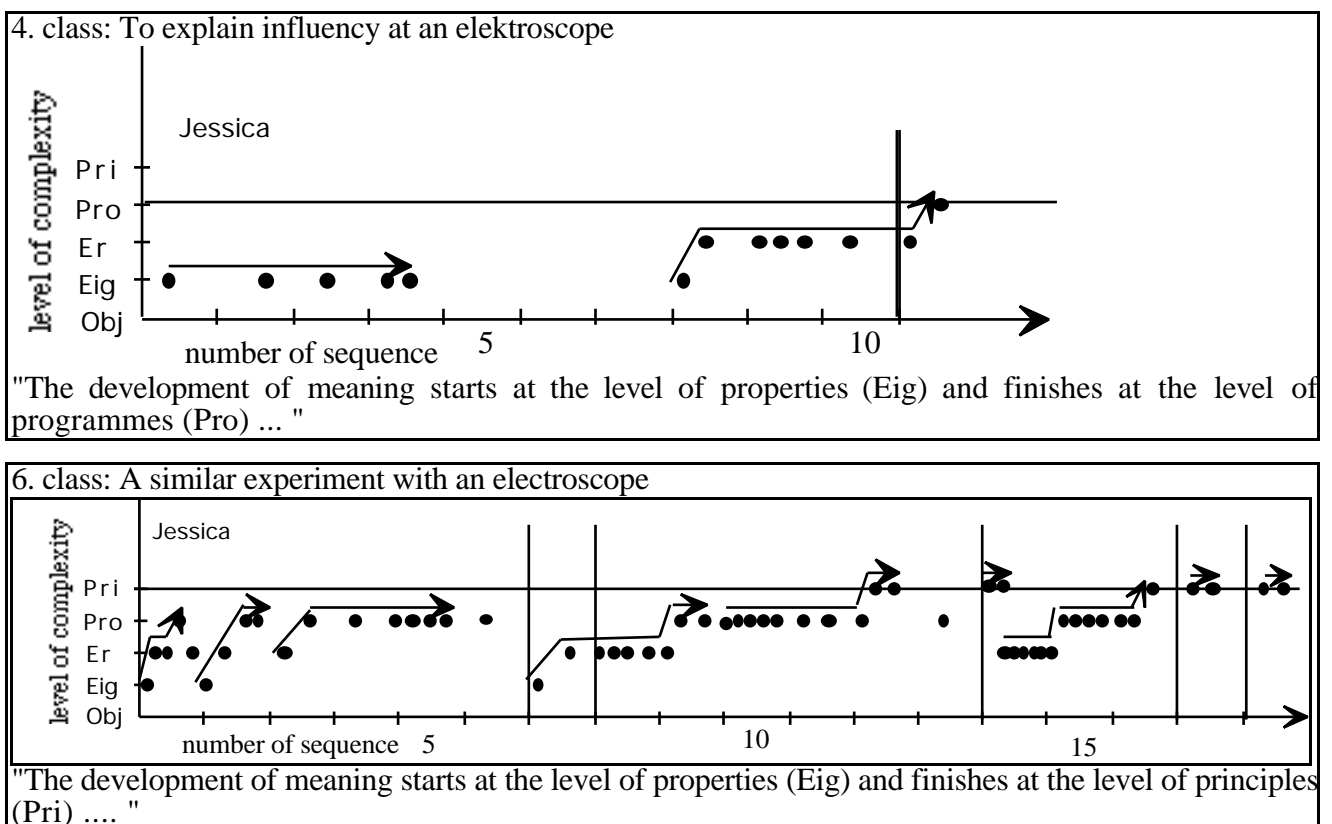


Fig. 14: Learning as development of constructions of higher complexity (Welzel, 1994, p. 197)

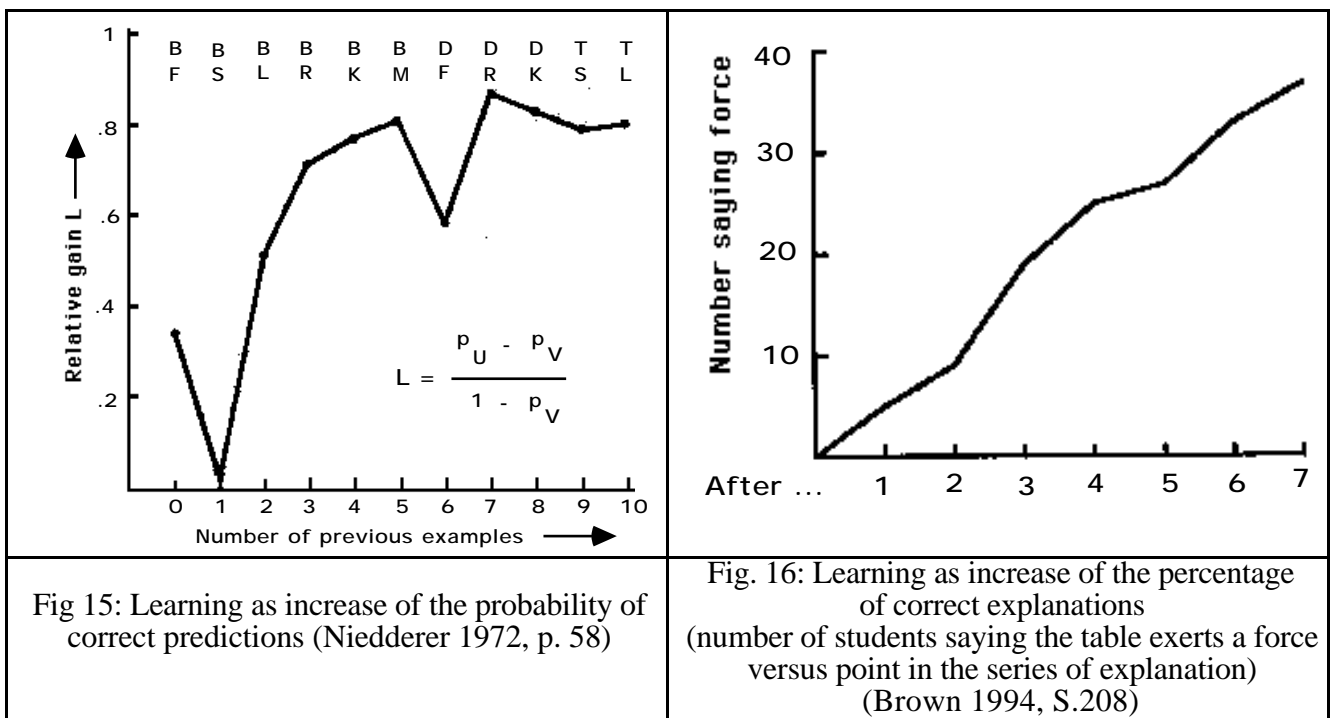
From the comparison of both diagrams the earlier achievement of higher levels of complexity in the 6th double lesson is to be interpreted as learning. The author determines learning as a process in the

course of which the student learns to arrive sooner and more successfully to higher levels of complexity in similar future problem solving situations:

*"The cognitive system has learned something if prior constructions of meaning and their development have effected that in new (similar) situations sooner successful actions are organised and thus sooner discrepancies between observation and expectation in the new situation are diminished. ... Learning thus means that those developments of meaning proving to be helpful are strengthened in the procedures generating them (and those not proving to be helpful are weakened), so that the strengthened procedures generate "their" processes with greater probability and the weakened with reduced probability at the next occasion."* (Welzel, 1994, p.32)

Learning as an increase of the "power" respectively "probability of use" of a cognitive element

Learning has also in its everyday language meaning something to do with the competence in the use of knowledge. In this sense learning can be understood as an increase of the "power" or "probability of use" of a cognitive element. Niedderer (1972) supplies an example by investigating the increase of number of correct predictions when connecting various sources and consumers in the electric circuit (see Fig. 15). In Brown (1994) there is a similar description to be regarded as an increase of probability of use of the correct answer ("counterforce of the table exerted on the book lying on the table" after the "treatment" of seven similar examples (see Fig. 16).



## Learning as an increase in the level of explanation

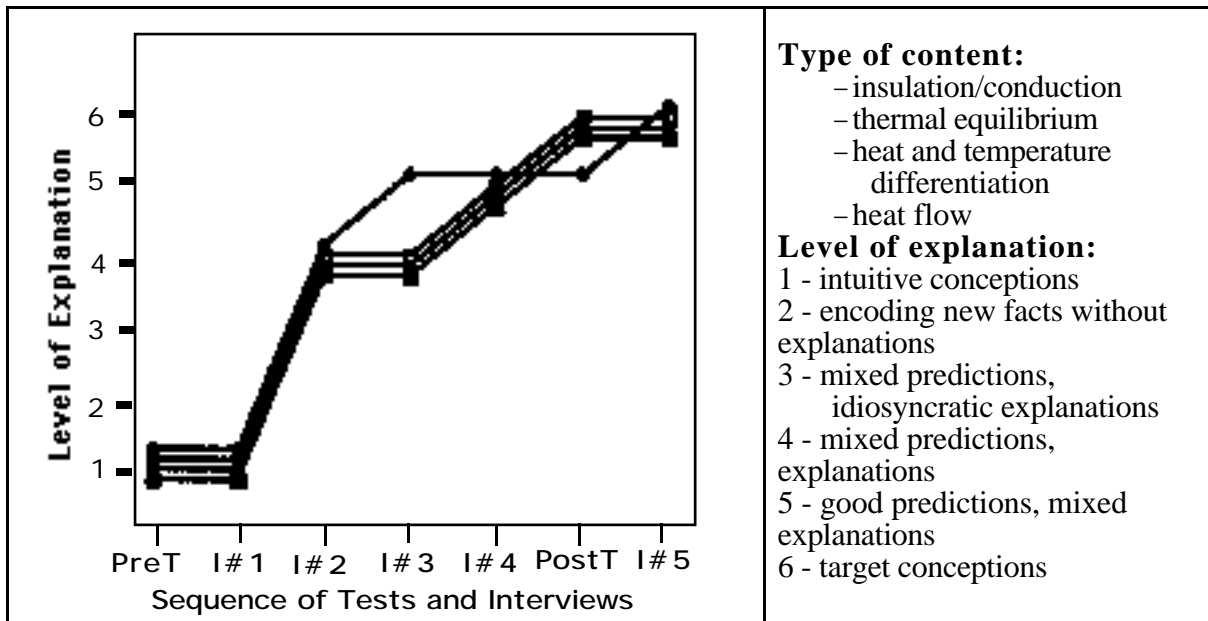


Fig. 17: Learning as increase of the level of explanation (Lewis, 1991)

A description taking up rather the qualitative characterisation of the modification of cognitive elements is found in Lewis (1991). She describes the modification of levels of explanations during instruction with respect to four different contextual dimensions. This increase of the level of explanation is gathered for individual students from the analysis of a total of seven interviews/tests and graphically shown in Fig.17.

### **4.3 Instructional conditions of learning**

#### Intermediate conceptions as "stepping stones"

Brown & Clement (1992) report on classroom experiments in mechanics leading to an improvement of successful learning by explicitly attempting to use students' intermediate concepts. The subject dealt with was, among others, the physical conception of inertia. As intermediate concepts the teacher used the following:

- "hold back tendency"
- "keeps going tendency"

The authors consider these intermediate concepts as stepping stones of learning. They are convinced by the results that explicitly aiming at these intermediate conceptions has improved the learning results and helps both students and teachers to clarify important points. Tiberghien (1997)<sup>3</sup> takes the same view.

#### Statement of resonances between teaching input and self development of the cognitive structure

In their study Niedderer & Goldberg (1995) start from a constructivist learning model and see the connection between the teaching offer (teacher information and behavior, texts, experiments, actions)

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<sup>3</sup> Paper to be published soon.

and actual learning as "resonance" ("compatibility" or "conceptual fit", Glasersfeld, 1992, p. 33) in the following sense: Depending on the individual cognitive structure of the student different parts of the learning offer have more or less significant effects. In case of positive effects of certain teaching inputs they speak of resonance between teaching information and cognitive system of the student. This idea has been formulated in a particularly impressive way by Ernst von Glasersfeld in a discussion during the Bremen workshop on learning process studies. He talked of a pizzicato violin sound (teaching input) which may bring back an echo in a room (cognitive construction) as a resonance as far as sound and structure of the room "fit together".

Such resonances Niedderer & Goldberg (1995) find when introducing the "language of electrons" in their above identified study which was done by the teacher only "incidentally". The students willingly responded to most of the teacher's information and went on constructing their own ideas thus being able to do substantial reasoning about current themselves. This is explained by the fact that the offered electron model of current permits the students to make use of numerous already existing cognitive tools (see the list shown above). Another portion of the positive resonance is put down to the high estimation of these students for atomic microscopic models as "true physics".

#### Adaptation of the level of complexity of the teacher to that of the students

Welzel and von Aufschnaiter (in personal notice) have following hypotheses on possible consequences for improvement of teaching out of their research results:

- teachers must be aware of and able to analyse the level of complexity used by their students. They have to adapt their own information to the students to their level of complexity.
- students have to get enough time to develop constructions on their present level of complexity.
- students' social construction processes in free working teams are of particular significance for the learning process.

With respect to the influence of interactions on learning environments (Welzel, 1994) it has to be stated on the basis of these results that even by interactions information cannot be transferred but that during interaction processes in the student's cognitive system are started. The course of these processes depends essentially on the cognitive system itself and its ability to link experiences in relation to the learning environment. Developments of meaning therefore are (more or less surprisingly) individual.

To promote the process of development of meaning therefore the student's experience must be able to be included in the interaction. As no one can know somebody else's experiences in their possibilities it is important to observe the actions of the learner in order to see on what level he solves problems at this moment and to give him chances for building up relations starting from this level.



## 5. Conclusions

- Learning is to be seen as self development of the cognitive system: Learning perhaps is more influenced by cognitive tools in the mind of the students than by specific types of teaching. Thus, learning processes in physics education with the aim of coming to concepts of physics frequently come to intermediate conceptions, determined by the application of those tools. These intermediate conceptions lie often between prior conceptions and the scientific conceptions. We can observe intermediate conceptions in students' thinking which were never intended by the teacher, sometimes not even recognised by him.
- In many cases many different types of teaching come to the same intermediate conceptions. Those intermediate conceptions which are characteristic for the dynamics of the development of the cognitive system itself, we call them attractors of the cognitive development of students in the specific content area.
- To analyze the role of basic cognitive tools in students' learning processes and their influence on resonance or non-resonance of learning with teaching is a research goal with high priority. Possible types of cognitive tools are: Basic conceptions like "particle", "fluid", "food" or "fuel"; basic schema or p-prims like Ohm's p-prim or the consumption schema; simple basic parts of natural language related to those other basic tools.
- There might be a new view on learning states after teaching: It might be a better picture of the final state of learning after teaching if we think of different layers with different "strength" and "status", which are activated by the student in different ways: some are easy and come first (high strength), others are more relevant (high status), but come later. So, giving more time in final examinations might be an important way to come to better results about knowledge of students after teaching.

## 6. References

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