Physics Learning as Cognitive Development

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Physics Learning as Cognitive Development

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Abstract
A theoretical perspective of physics learning processes as cognitive development is described, referring to theoretical frames and empirical results of other authors. Students' cognitive system is described with cognitive elements, classified according to different grain size. "Cognitive atoms" as elements with the smallest grain size - the basic building blocks of cognitive systems - are used by many authors with different terms (p-prims, facetts, cognitive tools, intuitive rules or reasoning primitives). Finally learning pathways are described, in some cases determined by "cognitive attractors". The final state of learning is analysed, and the basis law of cognitive development is formulated with respect to teaching.

Introduction

The idea of learning seen as a cognitive development is certainly not new. Already Wagenschein clearly developed the idea of learning as developmental process by introducing the term "genetic learning" in his work, for instance in his book "Children on their way to physics" (Wagenschein et al. 1973). Later-on Schenk and her group compared this model of genetic learning to a traditional so-called "science logic model of achieving competence" (Schenk et al. 1982, p. 6):

In a science logic model of achieving competence: The learner ...
1. ... learns a concept, if the concept is introduced with a term, a defining equation and a dimension.
2. ...transfers a mathematical operation on a physics relation in a formal way and thereby learns (understands!) also the physics relation.
3. ... fully assimilates a theory while learning it. At the end of the learning process he has completely reconstructed his mental structure so that it is in completely in line with the newly assimilated theory. He now describes all physical phenomena in a language fully integrating the assimilated theory, ...

The early "developmental" alternative has been "genetic learning" (Wagenschein, quotations from Schenk et al. 1982). Below the two theories are compared:

Formal Learning	Genetic Learning
· science logic · collect “learning stuff“ · “stock pile“ learning · “school" learning (in classroom)	· developmental logic · understand · assimilation and accumulation (Piaget) · applicable knowledge (not only in school)

In this paper, "physics learning as cognitive development" is to be understood both as research programme with corresponding empirical results and as a plea for genetic learning in physics instruction taking into account the of natural laws of learning as a developmental process.

Cognitive description of knowledge

Basic structure of cognition

Cognition is a shimmering term. We observe learners in situations where they show an observable behaviour. Accessible to empirical recording are thus the characteristics of the situation and the behaviour of persons in the situation. From these two known facts we draw conclusions about the characteristics of the person which are attributed to the brain and which are normally called knowledge, abilities, ideas etc. Talking about cognitive structure therefore means talking about models of the mind.

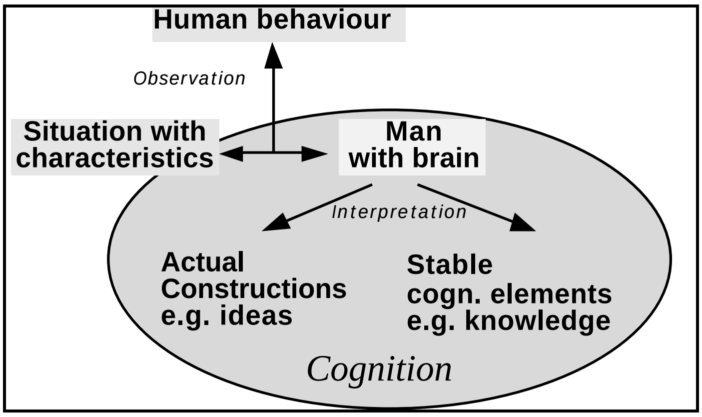


Figure 1. A model of the mind

Description of cognition therefore always refers to not directly observable models of basic thinking structures, which are concluded from pairs of observable situations and observable behaviour by interpretation (Schecker 1985, Viennot 1995).

Actual constructions

Cognitions can be differentiated with respect to their time structure. There are actual constructions (in the order of 10 seconds) and stable cognitive elements of various types, which are considered to be stable from hours to months or years. Examples for actual constructions are "mental representations" (Schnotz 1996), constructed meanings and ideas (von Aufschnaiter & Welzel 1997), and observations, questions, expectations, explanations and meanings (Niedderer & Schecker 1992).

Stable knowledge - different forms of description

Learning in this paper is understood as the modification of stable cognitive elements such as frames of thinking, knowledge, conceptions, interests and others. Therefore the different forms of description of stable knowledge are of particular importance.

<u>A hypothesised conceptual structure</u>

Vosniadou et al. (1998) suggest to use two levels of the cognitive structure of primary school children with respect to the force concept, one level of framework and one specific content oriented level, in this case relating to the concept of force. She obviously considers certain ontological and epistemological basic beliefs as determining factor for the children's concepts about force.

Mental models, cognitive schema, propositional representation

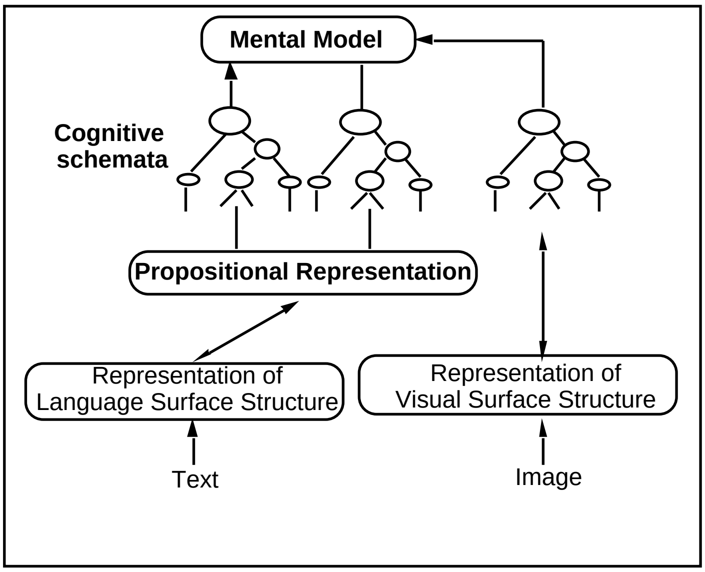


Figure 2. Mental models composed of symbolic parts (Schnotz 1996)

Based on Bruner's theory of cognitive development, Schnotz (1996) assumes that mental models are composed of symbolic parts - "propositional representations" - and iconic parts - "mental models" in the narrow sense. In this way different cognitive schema are build up and finally constitute a mental model in the wider sense.

Systems of knowledge in natural science ("Naturwissenschaftliche Erkenntnissysteme")

Wolze (1989) describes the complex network of theoretical and empirical knowledge as system of knowledge in natural science. It includes knowledge about its specific use. He explicitly describes the theoretical background of developmental processes and structures going on within these systems of a learner.

Learner theories

Following Schenk, Hericks (1993, S. 103) defines learner theories "as consistent systems of terms, knowledge and concepts, which students build up on their way to the valid physical theories and which they use in different situations ..."

A structure to represent students' knowledge

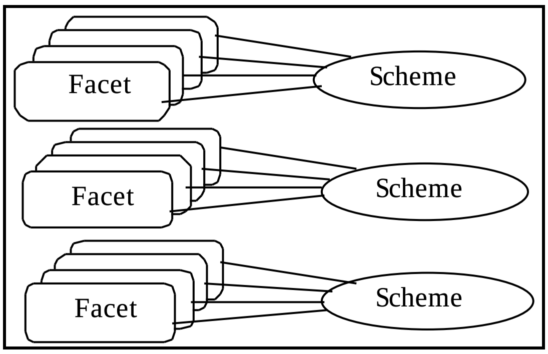


Figure 3. Stable knowledge elements according as two levels (Galili 1998)

Galili (1998) has described stable knowledge elements on two levels as "schemes" and "facets" and given examples from optics. His term "scheme" is similar to Schnotz's cognitive schema (see Figure 3).

Cognitive system

The idea to describe knowledge as cognitive system is also pursued by diSessa (1993) who links understanding of learning to a developmental process ("development of knowledge systems"). Based on the concept "matrix of understanding" (MOU, German: "Vorverständnis", see Niedderer 1982, Schecker 1985) Niedderer and Schecker attempt to show the actual constructions and the different types of stable cognitive elements in a model of the cognitive system (Niedderer&Schecker 1992, Niedderer 1996, 1997).

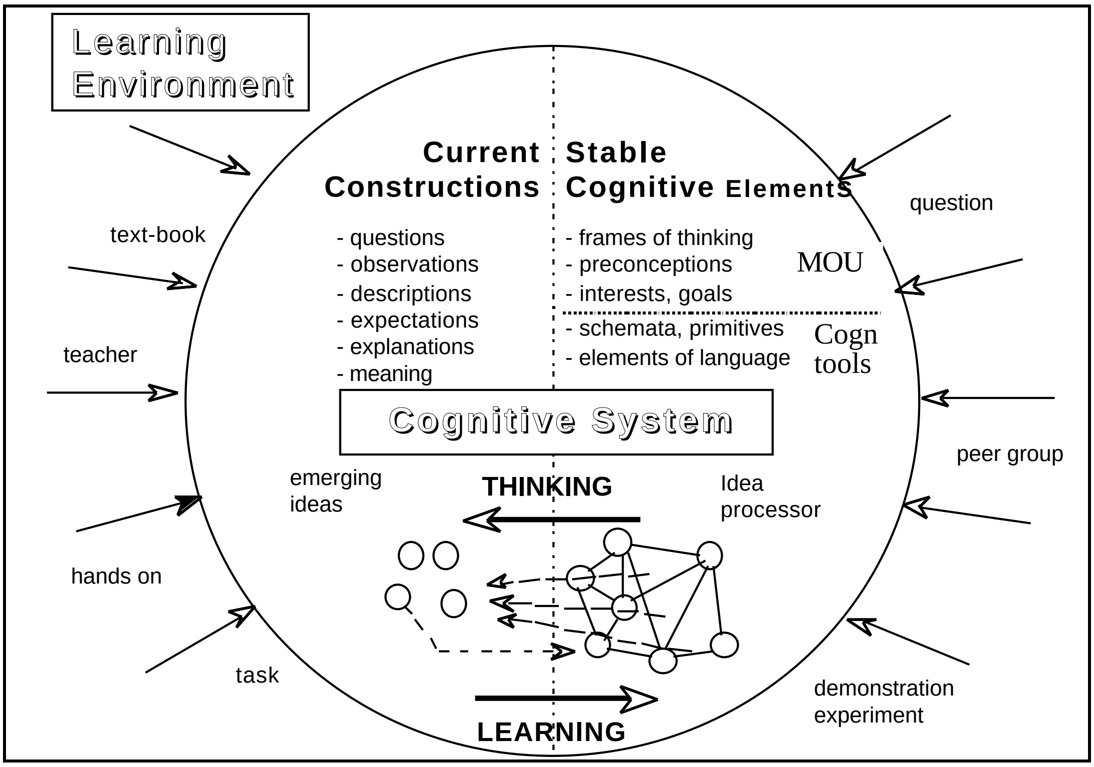


Figure 4. Model of the cognitive system showing the actual constructions and the different types of stable cognitive elements. (Niedderer&Schecker 1992, Niedderer 1996, 1997)

The distinction of "actual" and "stable" (see above) is of particular importance for the interpretative analysis of empirical data. The stability of an (intermediate) conception is empirically tested with the question whether this conceptions is used (reconstructed) again and again during a certain period of time in similar contexts.

Under the influence of a learning environment and based on stable cognitive elements the individual develops actual ideas which can be more and more successful and lead to new stable cognitive elements.

The search for basic elements

The idea of "cognitive atoms"

The idea to describe cognitive structures by means of basic elements (cognitive atoms, building blocks, and tools) has been stimulated by the discussion on the nature of conceptions and knowledge (Fischer 1994, S.30). On the one hand, for many years research results consistently were described as repeatedly found students' conceptions related to certain domains of physics. This was accumulated as a body of agreed knowledge about such stable elements of the cognitive system (Pfund&Duit 2000). On the other hand - partly initiated (stimulated) by neurobiological views of structure and function of the human brain – the idea of those conceptions all being stored in the mind like in a department store (Aufschnaiter & Welzel 1997) seemed no more to be very plausible. It seems, however, plausible to assume that certain more elementary and basic "cognitive tools" (Niedderer 1996, 1997) are represented in the mind, and that they, in interaction with the particular situation, produce these conceptions. DiSessa (1993) describes the aim as follows: "The aim for this work is to understand the 'intuitive sense of mechanism' that accounts for common sense predictions, expectations, explanations, and judgements of plausibility concerning mechanical causal situations, and to understand how those intuitive ideas contribute to and develop into 'school physics'." DiSessa wants "to describe the size and character of the knowledge structures involved. Relevant but insufficiently precise categories are ideas, categories, concepts, models, theories, etc."

Knowledge in pieces - "p-prims"

The "p-prims" (phenomenological primitives) introduced by diSessa (1993) are described by himself as follows: "P-prims are rather short knowledge structures (typically involving configurations of only a few parts) that act largely by being recognised ... in the system's behaviour or hypothesised behaviour. ... p-prims become the intuitive equivalent of physics laws; they may explain other phenomena, but are not themselves explained with the knowledge system." The best known example of a p-prim is the so-called "Ohm's p-prim": "An agent which is the locus of an impetus that acts against a resistance to produce some sort of result."

Facets of knowledge

Minstrell (1992) describes the idea of "facets of students' knowledge and reasoning": "In our descriptions of students' knowledge, we are identifying and cataloguing the pieces of knowledge or reasoning that students seem to be applying in problem situations. We are calling these pieces 'facets'. A facet is a convenient unit of thought, a piece of knowledge or a strategy seemingly used by the student in addressing a particular situation." In this work Minstrell is well aware of the problem of the "grain size of knowledge" when cataloguing long lists of such facets found in empirical investigations.

Reasoning primitives

Wittmann (1998, 67) describes "reasoning primitives": "In this sense, a primitive is a common and small logical building block that lets us describe basic elements of common events in many different situations. A suitable analogy can be made to the way physicists and chemists think of the atom. In many settings, the atom is the smallest relevant description of nature. One atom (the primitive) can be part of many different types of molecules (the situation). Of course, the substructure of the atom is of great interest, but not always relevant to the specific model one is considering. In the same way, one can discuss elements of primitives and how they develop, but the primitive itself is a relevant grain size ... We can think of primitives as the building blocks with which people build their thinking. Primitives can help simplify both everyday and physics reasoning situations." As the most important example of a reasoning primitive in his analysis of students' understanding in wave acoustics he describes the "object as point primitive (PP)": "The object as point primitive (henceforth called the point primitive) is based on observations of student descriptions of waves, but has a more general applicability." And later: "The point primitive is characterised by the description of a large, global object or wave in terms of a single point." This primitive is very similar to our cognitive tool "particle" (see below).

Cognitive tools

The term cognitive tool has been introduced in different ways as "hypothetical cognitive tools" (Niedderer 1996, 1997) and as "unknown cognitive tools" ("modules") (Aufschnaiter & Welzel 1997). Subsequently we consider cognitive tools as stable cognitive elements, which can be regarded qualitatively as "elementary" and as stable already long before the actually analysed learning process. From the analysis of intermediate states in the learning process we gather hypotheses about such cognitive tools, which could be used by the students in the knowledge construction process (Niedderer & Goldberg 1995, 1996, Petri & Niedderer 1998 a).

Intuitive rules

Tirosh, Stavy, and Cohen (1998).) talk of intuitive rules as elementary building blocks.

Conceptions: represented or produced?

The two research groups Aufschnaiter and Niedderer in the Bremen Institute of Physics Education have different views on stable cognitive elements (in particular on conceptions) and on cognitive elements, characterised in the following summary:

Common views

- Conceptions are produced again and again in situations with the assistance of cognitive tools. One cannot "have" complex conceptions.
- Learning as development of knowledge

Different or contrary views

Niedderer group	**von Aufschnaiter group**
· Knowledge is described in the form of content related cognitive elements (e.g. conceptions) - interpreted as again and again repeated constructions.	· Knowledge is described content specific by the level of complexity achieved by the student.
· Knowledge development as modification of stable cognitive elements, developed with the assistance of cognitive tools.	· Development of knowledge as modification of the complexity of content related conceptions.
· A content specific description of hypothetical cognitive tools is a crucial progress on the way to describe learning as a process of development.	· Cognitive tools are very elementary and therefore not (yet) accessible to content specific didactic research.

Developmental structures

Using the term development we express the belief that learning processes also in physics are strongly determined by the developmental possibilities of the individual cognitive system. The aim is to recognise learning as a process of development of the cognitive system, which is determined both by the structure and developmental potentials of this system and by the environmental input from teaching. In this sense, Schnotz (1996) understands Bruner's book of 1966 as a "theory of cognitive development".

Conceptual change / growth / development

Duit (1996) characterises the relation between conceptual change and cognitive development as follows: "Learning is regarded as a process of cognitive development leading from certain pre-instructional conceptions, i.e. already existing in the cognitive structure, to a scientific view." In this context conceptual change means conceptual growth as well as conceptual change.

Learning and self-development

Especially the following contributions are committed to the idea of development in the learning process:

- Wolze (1989) "On the development of scientific knowledge systems in learning processes" and
- von Aufschnaiter (1991) "Learning is self development of a cognitive system"

Von Aufschnaiter&Welzel (1997) speak of knowledge transfer by knowledge development, and Fischer (1994, p.25) describes learning as the development of subjective areas of experience. Also diSessa (1993) speaks of "system development" and formulates the aim "to understand the genesis and development of the system."

Systems and system dynamics

Speaking of systems, one speaks in general of structures composed of elements of different kinds and their interrelations. Speaking of system dynamics means that the system is able to generate modifications of itself by totally internal processes *and/or* in interrelation with the instructional environment. Learning from this point of view is a process of development in which the self-development of the cognitive system in interrelation with the learning environment plays a crucial role. The impact of the learning environment is, however, only indirect, its effect is limited by the developmental possibilities of the actual state of development of the system.

Learning as cognitive development - an analogy

By using the following analogy the idea of development can be illustrated.

Growth	**Learning**
· rain	· teaching aids
· climate	· rewarding
· genetic inheritage	· cognitive tools
· structure of the plant	· cognitive system
· prior growth	· pre-conception
· gardener	· teacher

Using the term "development" we wish to stress that, besides the influence of the learning environment, learning is determined essentially by the autonomous laws of the system development of the individual cognitive system. For future research on learning processes the main direction is therefore the description of the cognitive system and the possibilities of its development.

Empirical results on aspects of physics learning as a cognitive development

Achievable next conceptions as steps of development

Intermediate conceptions as final results of learning

A noticeable indication for developmental possibilities being a limiting factor for learning are the numerous results of investigations showing how learning leads to other than the intended results. Galili et al. (1993) gave a good example by describing conceptions students reached after instruction on geometrical optics as intermediate conceptions. The main intermediate conception at the end was analysed as a hybrid conception between prior conceptions and intended physics concept. At the beginning the authors found a holistic conception of image formation. They aimed at achieving a concept of image formation in the sense of geometrical optics taking in consideration that a great number of rays emanate from each point of the object. The empirical results showed that after instruction students had a better but still inadequate conception of image formation which the authors call "relevant ray diagram". This conception after instruction is also called "hybrid conceptualisation of image formation" which is characterised by using only few selected rays for image formation. With this conception students in some cases fail to reach adequate explanations of events, such as the fuzziness of an image at greater distance of the screen.

<u>Intermediate conceptions as possible new learning goals</u>

Similar results have been found in a study of Tiberghien (1997). The "step of learning" achieved by students at the end of the teaching sequence was significantly different from the "knowledge to be taught". The new idea in Tiberghien's study is her suggestion to consider the intermediate conceptions empirically found at the end of the teaching sequence as new, more realistic learning goals.

> *"The aim is to allow the design of teaching situations more relevant for learning ... These results show a gap between the teaching aim and the students' acquisition. What is learned by the students was not intended by the designers of the teaching sequence. This gap leads us to propose a modification of the knowledge to be taught. In particular the learning step concerning the insulation situations is meaningful enough to be considered as an intermediary notion between what is usually intended in curriculum and students' prior knowledge."* Tiberghien (1997).

<u>Intermediate conceptions as "stepping stones"</u>

Brown & Clement (1992) suggested in a similar way to use preliminary terms on the way to the physical term inertia. In detail they propose that the teacher should explicitly aim at the following two "intermediate conceptions" before introducing the concept of inertia:

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

They regard these preliminary conceptions as "stepping stones" for learning the concept of inertia. Their empirical results seem to show that explicitly aiming at such intermediate conceptions veritably improves learning effects.

<u>Intermediate conceptions as "conceptual dynamics" in the process of learning</u>

Thornton (1995) describes learning processes as "conceptual dynamics" and the actual state of knowledge as "view". He distinguishes different kinds of "student views" and finally the "physics view" aimed at by teaching

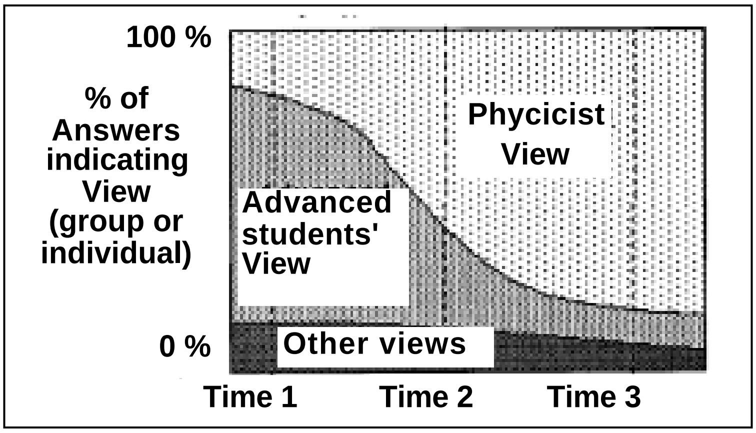


Figure 5. A model of the gradual transition from two different students' views ("advanced students' view", "other") to a "physicists' view" (Thornton 1995)

The illustration to the left shows sort of a model of the gradual transition from two different students' views ("advanced students' view", "other") to a "physicist view" as it results from the average data measured at the three times (on average). However, it can be seen as a model of learning of the individual student too.

<u>Learning pathways as progressively passed intermediate conceptions</u>

From the discussions at the international workshop "Research in Physics Learning" 1991 (Duit, Goldberg & Niedderer 1992) in Bremen resulted "learning pathway" as a crucial term to describe learning processes. The notion of learning pathways serves at first for a qualitative description of learning processes with a stroboscopic picture of a sequence of stable or meta-stable intermediate conceptions, followed by a detailed analysis of developmental conceptual changes. In the investigations carried out in Bremen these are often recorded and analysed for a single student's learning process.

The first subsequent example is from mechanics, later we show the learning pathway recorded in a study on electric circuits, and we close with a learning pathway in the field of quantum atomic physics.

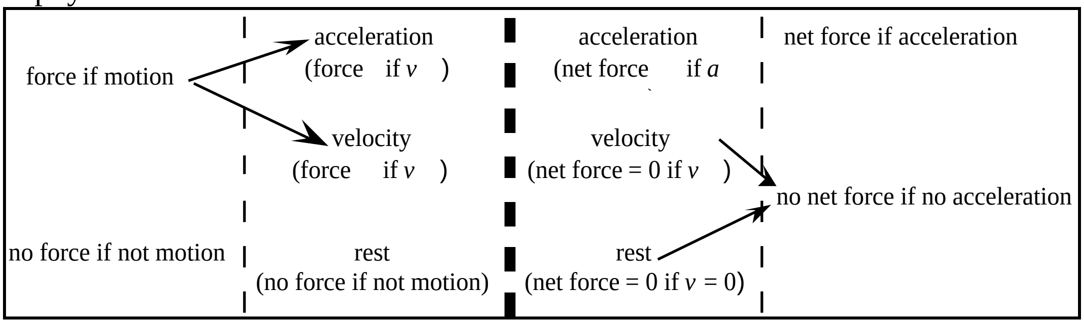


Figure 6. A series of conceptual changes described over four stations. (Dykstra 1992)

In this illustration of a series of conceptual changes (Dykstra 1992), the development of students' conceptions related to the force concept are described over four stations. The differentiation of acceleration and velocity and their correct interrelations are shown as the most important steps.

Our second example shows a learning pathway in the field of electrical circuits (see Figure 7).

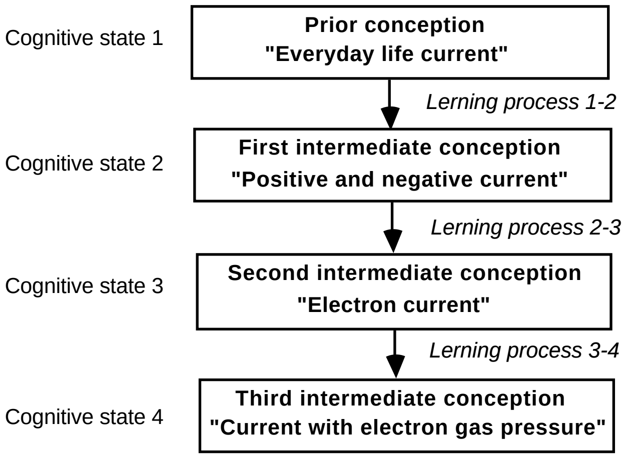


Figure 7. Overview of learning pathway and learning processes(Niedderer&Goldberg 1995, 1996)

In this study conceptions of three girl students in a course for prospective primary school teachers are analysed. The process starts with the well known initial conception and leads via two intermediate conceptions "positive and negative current" and "electron current" to a final conception "current with electron pressure" which still has significant deficits compared to the scientific and to the intended concept.

In our third example, Petri (1996) describes a learning pathway of one student Carl in a course on quantum atomic physics.

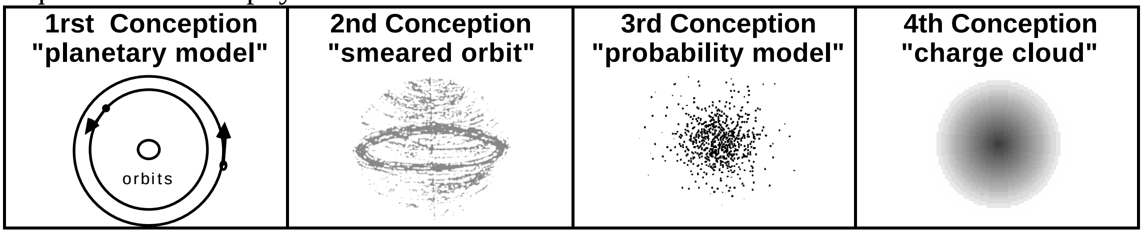


Figure 8. Four atom models successively created by a student (after Petri&Niedderer 1998 a, b)

This learning process in the field of conceptions of the atom and their development in a quantum atomic physics advanced course in the 13th grade is characterised below by four atom models successively created by the student. They are represented only by graphs here, but they are presented in detail with evidences and discussion elsewhere (Petri&Niedderer 1998a, b)

<u>Intermediate conceptions as “cognitive attractors”</u>

We introduced the term "cognitive attractor" in order to describe such intermediate conceptions, which are found frequently in a specific content domain, often independent from the particular teaching approach. They are thus a direct evidence for laws of self-development of the cognitive system in physics learning. In both examples stated below these conceptions had not been intended by the teacher. Both observed intermediate conceptions are found as a result in several studies of other authors as well.

The first example comes from our investigation of the learning processes of three American college students (Niedderer & Goldberg 1995, 1996). During the experimental task to lighten a bulb with a mono cell, and subsequent tasks in writing, students developed a modified view of the electric circuit. This intermediate conception was described as "positive and negative current": Positive and negative charges are flowing in two different connections from the battery (+, -) to the bulb (low end, thread). By coming together in the bulb they produce light. Similar results have been observed by Shipstone ("clashing currents conception", 1985) and Schwedes et al. (1992).

The second example is the formation of an intermediate conception "smeared orbits" in the atom (Petri 1996). This intermediate conception can come up in three different forms, as a wave orbit, as a smeared fuzzy orbit or as the maximum of proximate orbits (see figure below). This conception has also been observed earlier by other authors (Bayer 1986, Bethge 1988).

Analysis of physics learning as cognitive development

<u>Preconceptions as cognitive building blocks</u>

One special idea about cognitive development has been found rather early by several authors: The possibility to regard students' (mis-) conceptions not only as an obstacle of instruction to be overcome but to make use of such conceptions in students' minds as modules for the construction of new improved conceptions. In their article "Not all preconceptions are misconceptions: Finding 'anchoring conceptions' for grounding instruction on students' intuition" (Clement et al. 1989), the authors explicitly look for such conceptions that could serve as a starting point for the construction of intended improved physical conceptions. With

Newton's 3rd axiom using the example "book on the table", students often do not see a force exerted from the table on the book. For this problem, the authors have found several conceptions, which can improve the cognitive development, for example students' conceptions when pressing their own hand on a spring or when holding a heavy book in their own hand.

Theoretical analysis of the development of intermediate conceptions from the interrelation between cognitive tools and teaching

Niedderer and Goldberg (1995, 1996) describe the development of a new intermediate conception "electron current" not intended by the teacher. It is found during instruction in an open discussion on the electric circuit in which the teacher intends to introduce the concept of electron pressure and the concept of voltage as electron pressure difference. In this context the teacher uses the term 'electron' only by the way, but the students adopt it readily and with great resonance. Evidence of the effect of this intermediate conception could be found in the present and the following double lesson. The transcribed dialogues between the teacher and the students clearly prove the great resonance in students' thinking was caused by working with the term 'electron'. The cognitive analysis of this positive learning process will work with the assumption of the following plausible cognitive tools:

Hypothetical "cognitive tools", contributing to the "electron current" conception:

- frame: Electron is a modern term used by experts
- cognitive tools related to physics (elementary conceptions)
  - The "electron" as "particle"
  - "Positive" and "negative" charges; repulsion and attraction
- cognitive tools from everyday life (linguistic elements)
  - particles can "move"; they can "kick" (push) other particles or atoms
  - the "number" of particles can easily be conceived
  - particles "need free space" in order to be able to move.

We interpret the observed high motivation by the experience of the learner's own competence which goes along with this cognitive development. This is also the impetus for the cognitive development. In the sense of Glasersfeld (1992), we interpret the process of development as resonance between learning environment and cognitive system.

In a second example we interpret the development of an intermediate conception "smeared orbit" in teaching quantum atomic physics in the 13th grade (Petri & Niedderer 1998a) from the interrelation between cognitive tools and instruction (content of teaching) as shown above.

Cognitive tools	Instruction
· An "electron" is a "particle". (Elementary conception, Bormann 1987) · An atom consists of a nucleus and of electrons circulating around it. (Elementary conception, Knote 1976, Harrison et al. 1996) · A particle can move. (Linguistic element)	· For quanta an uncertainty relation with the Planck' constant h is valid. · With the electron deflection a wave conception on electrons is introduced. · The Psi - function states information about possibilities and probabilities.

It seems plausible that from interrelation between the mentioned cognitive tools and the mentioned central teaching content intermediate conceptions in the above identified three possible forms, which have, in fact, been observed (Figure 9).

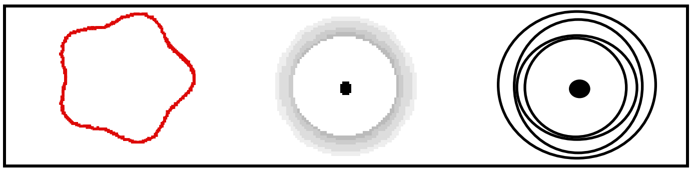


Figure 9. Three intermediate atom conceptions (Petri&Niedderer 1998a)

Evidences for these intermediate conceptions come from the following statements of student Carl (C) during instruction, (Petri 1996):

First form of intermediate conception:
C: That can also be such an orbit. Perhaps such a swinging orbit.
Second form of intermediate conception:
C: ... And about this electron - that is, in fact, a quantum - we can say rather precisely, that it moves on this orbit. (...)
C. Not really precisely - That isn't possible in quantum mechanics.!
Third form of intermediate conception:
C: Does Paul (another student, H.N.) imagine that this shell is sort of area where the electron can move on? (Carl's hands make circulating movements in different directions) (...)

Final state after learning

Different ideas on the final state

Already in the introductory "science logic model of competence achievement" Schenk (1982) referred to the problem of the final state after a learning process. Probably among teachers or science education staff the expectation is prevailing that the final state after learning is similar to the aims and intentions of the teacher. Everything else is interpreted as failure. According to recent theoretical considerations and empirical results, however, it has to be assumed that the final state after learning always is a complex structure, consisting simultaneously of prior conceptions and new (intended) conceptions, of multiple frameworks, sometimes clearly separated but often mixed or confused.

The final state as "space of possible representational systems"

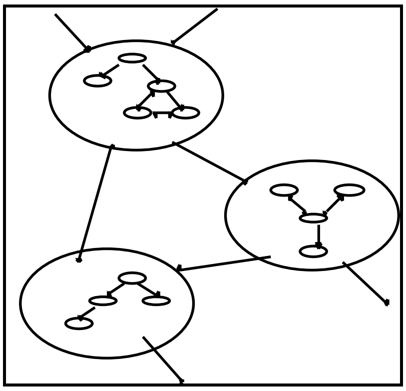


Figure 10. Graph of a simultaneous existence of heterogeneous representations

In his habilitation (second dissertation) in educational psychology related to problem solving in physics, Plötzner (1998) handles the final state after a learning process as a "space of possible representational systems" and a "problem space of second order". In our figure from his work this is shown in a graph as a simultaneous existence of heterogeneous representations (e.g. mental models).

Co-existence of conceptions

One of the earliest evidences for the co-existence of several conceptions after instruction is Scott's work (1987, 1992). He did a qualitative analysis of the dialogues with one student Sharon. He showed that after instruction on a particle model of gases, Sharon preferably uses the new model. But she also describes the advantages of the prior continuous model - for example in everyday communication. So she is able to activate both conceptions in parallel and clearly separated.

Parallel processing

> *"In some of the examples described above, students could be described as using more than a single primitive (or fact) in their reasoning. For example, in Clement's coin toss problem, it was possible to describe some students as using both the actuating agency and dying away primitives. In order to describe the manner in which multiple primitives are used by students, we can ask how students connect primitives in their reasoning." (Wittmann 1998, 75)*

Multi-layered understanding

> *"Primitive conceptions can persist alongside more advanced conceptions, even with respect to one task. They can act as useful recognition pathways into higher order conceptions, but also as barriers and misleading elements in thinking." (Tytler (1998, 909). "Children can generate a range of conceptions to create a multi-layered understanding of a phenomenon." (910). "Children are capable of generating a range of conceptions they bring to bear on one task, in trying to generate a satisfying explanation, expressing what might be thought of as 'multiple perspectives' on the same reality." (912)*

The final state modelled by different layers with different strength and status

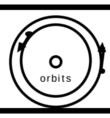
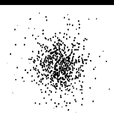
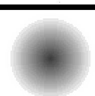
Final state of Carl's cognitive system "atom"			
Layer of the cognitive system		Strength	Status
planetary model		high	low
probability model		medium	medium
electron cloud		medium	high

Figure 11. A cognitive system 'atom' consisting of several layers (Petri 1996, Petri&Niedderer 1998 a)

Petri and Niedderer (Petri 1996, Petri&Niedderer 1998) describe the final state of Carl's cognitive system "atom" as consisting of several layers characterised by their individual strength (= probability of use) and their individual status (= assignment of physics correctness). This representation has been gathered from the interpretive analysis of transcripts during the final part of instruction, from an interview directly after the instruction period, and from an interview three months after instruction. It describes in detail the following facts:

- At the end of the instruction period Carl uses apart from the intended electron cloud model also other models to describe the atom, in particular the planetary model and the probability model.
- In many, especially in new contexts, Carl starts using the older planetary model. This conception seems to be most easily available. This cognitive layer thus has the highest "strength".
- Often, however, it is sufficient that the interviewer just waits a little or gives a small hint to get Carl to use especially the electron cloud model on his own. This is usually accompanied by statements such as "that's much better" or "that helped me a lot during instruction". In our interpretation these statements show that this conception has the highest status for him

We believe that this idea of the final state, comprising not only one conception - either right or wrong - but several simultaneously co-existing conceptions or layers throws a new light on numerous results about learning.

Often in investigations on conceptions and learning, only the prior conceptions are found after teaching, thus seeing no learning success. Perhaps this is a result of fast and short questions, resulting in addressing only the easiest and most confident layer (with high strength), but not the 'deeper' layers related to those conceptions, which were intended by teaching. By using more open-ended questions or special in-depth interviews, more learning effects could be found.

Motivation as the energy for development

Each development requires some 'driving energy'. In the sense of this approach we interpret motivation as energy for development. The approaches "learning in a meaningful context" (Muckenfuß 1995) and "physics as life experience" ("Erlebniswelt Physik", Labudde 1993) try to work out the subjective and objective meaning of physics in children's lives and to use them for physics instruction. We referred already above to another important aspect of motivation, the feedback from experiencing own competence in doing physics. Some results show a strong correlation between motivation and experiencing competence (C.v. Aufschnaiter 1999). Related to this basic idea, we started 1990 to introduc " mini projects" in introductory physics university courses in Bremen. Students were allowed to work on their own ideas and questions during the last three weeks of laboratory work in those courses. This gives them more "ownership" and experiencing their own competence, resulting a high motivation. Students definitely worked harder as usual in these self-determined mini projects and for their final presentations. Similar observations have been made in the Bremen research project "cross-subject environmental projects biology/physics, a concept for combining teaching in courses and projects in upper secondary, (KUP)". Also in this project the self-determined task and the own responsibility for the set up and presentation of the results found, leads to an astonishingly high level of motivation and high amount of work invested in the projects.

The law of development in teaching and learning

On a first glance, the two following views on teaching and learning seem to be intransigent contrasts:

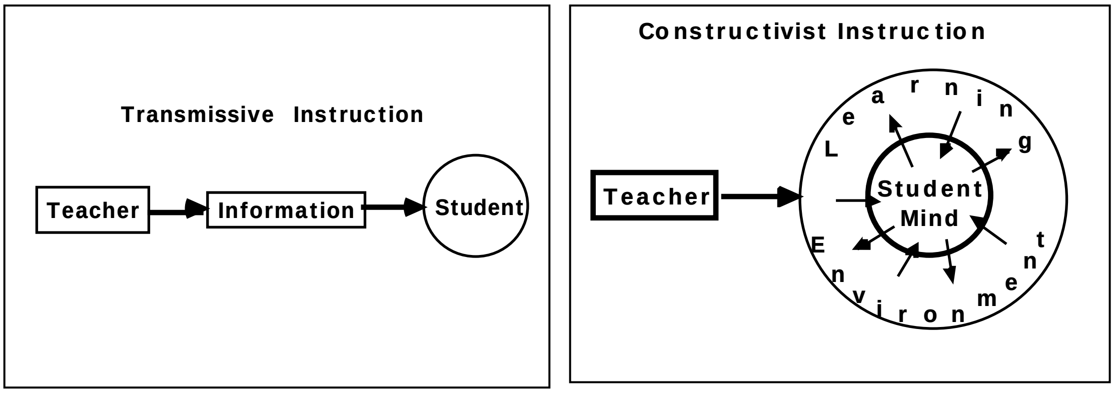


Figure 12. Two views on teaching and learning

It must be considered, however, that the principle of "learning as cognitive development" is valid for all types of teaching strategies, even if the teacher follows a pure lecturing method. Instruction practice is determined by a large number of different approaches. Many of those are very important for teaching, and this is also true for the lecturing type instruction. Vygotsky (1978) offers a combining idea. He suggests two different levels of development: the "actual developmental level" and the "zone of proximal development". He describes the meaning of the two development levels as follows: "That what is the zone of proximal development today will be actual developmental level tomorrow. That is what a child can do with assistance to day she will be able to do by herself tomorrow."

Learning *always* works as a developmental process of the cognitive system. Learning environments, however, can influence this process. In this sense I plead for a combination of

- lecturing and problem solving instruction
- teacher and student oriented instruction
- course and project instruction.

In Vygotsky's sense they seem to have complementary functions for learning, while their inscrutable merge in the traditional way of teaching (so-called "development by questioning", German: "Fragend-entwickelnder Unterricht") probably is an impediment for the cognitive development of the student. If we distinguish in this sense between "formal" and "genetic" teaching - not learning - the following is true for both of them: Learning cannot directly be determined by the teacher, learning is a process of development of the cognitive system in interrelation with the learning environment.

It is only the learning environment that can be determined by the teacher.

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