Learning process studies - aims, theoretical approaches, methods and selected results

7. ESERA Summerschool

Braga, Portugal

Universität Bremen
Institut für Didaktik der Naturwissenschaften
Abt. Physikdidaktik

Hans Niedderer

Hans.Niedderer@mdh.se

http://www.idn.uni-bremen.de/idpstart.php

KARLSTADS UNIVERSITET

Introduction

- 1991 International workshop in Bremen on "Research in Physics Learning - Theoretical Issues and Empirical Studies" (Proceedings: Duit, Goldberg, Niedderer 1992)
- From studies on students' alternative conceptions => studies on learning pathways / conceptual change
- First learning pathway study from Scott (1987,1992)

Nine "needs" from 1991 (Niedderer, Goldberg, Duit 1992)

(1) Need "to document learning pathways for different content areas in physics"

(2) Need "to construct ways of describing cognitive systems that are useful to researchers in physics education"

(3) Need "to develop research methodologies that would be appropriate for carrying out learning studies".

(4) Need "to document changes in student's conceptual ecology".

(5) Need "to examine issues regarding conceptual change".

(6) Need "to develop instructional strategies and materials based on results of learning studies in specific content areas".

(7) Need "to consider the appropriate role of the teacher in a constructivist classroom".

(8) Need "to promote teachers' (pre-college and college) awareness of research on student learning".

(9) Need "to promote communication and collaboration among cognitive scientists, psychologists, science educators and others involved in physics learning".

Institut für IDP Didaktik der Physik

Nine "needs" from 1991

(1) Need "to document learning pathways for different content areas in physics"

(2) Need "to construct ways of describing cognitive systems that are useful to researchers in physics education"

(3) Need "to develop research methodologies that would be appropriate for carrying out learning studies".

(4) Need "to document changes in student's conceptual ecology".

(5) Need "to examine issues regarding conceptual change".

(6) Need "to develop instructional strategies and materials based on results of learning studies in specific content areas".

(7) Need "to consider the appropriate role of the teacher in a constructivist classroom".

(8) Need "to promote teachers' (pre-college and college) awareness of research on student learning".

(9) Need "to promote communication and collaboration among cognitive scientists, psychologists, science educators and others involved in physics learning".

Defining "learning process studies"

- Data from "during" learning
- related to some form of conceptual change
  ... building on the most successfull research line in science education: alternative conceptions (Duit 2006)
- Similar to longitudinal studies?

Institut für IDP Didaktik der Physik

Four, more recent examples of learning process studies

Petri, J., Niedderer, H. (1998). A learning pathway in high-school level quantum atomic physics.

Psillos, D. & Kariotoglou, P. (1999). Teaching fluids: intended knowledge and students' actual conceptual evolution.

Taber, K. S. (2001). Shifting sands: A case study of conceptual development as competition between alternative conceptions.

Clement, J. and Steinberg, M. (2002). Step-wise evolution of models of electric circuits: A “learning-aloud” case study.

Institut für IDP Didaktik der Physik

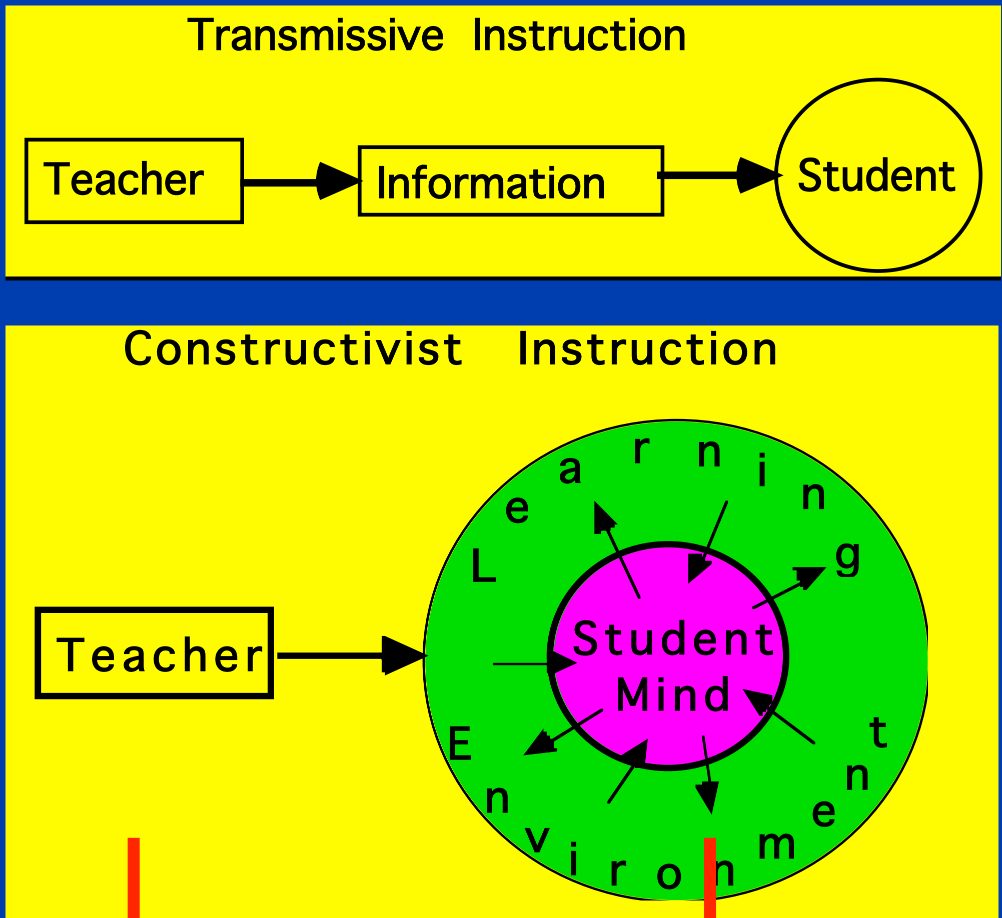
Theoretical Approaches

Teaching and learning

- Constructivist view
- Social constructivism
- Socio-cultural view => focusing on teaching

- => Here: Constructivist view, focusing on learning

Constructivist view of teaching and learning



Teacher's intented conceptions

Student's own constructions "intermediate conceptions"

Theoretical Approaches

Basic statements/assumptions

Institut für IDP Didaktik der Physik

Basic statement/assumption about learning (1)

Learning science means always conceptual change ...

- ... because of the fundamental differences in "Cognition in Scientific and Everyday Domains" (Reif & Larkin 1991)

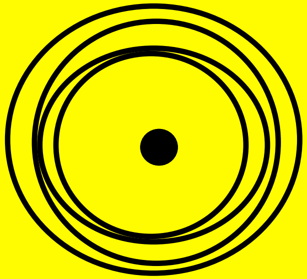
Basic statement /assumption about learning (2)

The learning outcome is always different from teacher's intentions.

- The "gap" (McDermott 1991):
  "What we teach and what is learned—Closing the gap"
- Knowledge to be taught is different from students' step of learning (Tiberghien 1997)
- "Learning as self-development of a cognitive system" (von Aufschnaiter, 1991)

Evidence for self-development: "Cognitive attractor"

Example:

The conception "smeared orbits model of the atom"	
Propositional representation	The orbits are combined with a quantum idea of probability, wave or uncertainty, thus becoming a mixture between orbits and orbitals.
Image representation	  Bayer (1985)

Found by different authors, with different teaching approaches: Bayer 1985, Bethge 1988, Petri 1996

Basic statement/assumption about learning (3)

Learning is content specific (Seiler 1971).

- For every content area exist only a limited number of different alternative conceptions
  Similar assumption in phenomenography: limited number of different ways to see a certain phenomenon (Marton & Booth 1999)
- Marton: learning is always the learning of something!

Basic statement/assumption about learning (4)

For every content area (theme of a teaching unit) **exists only a limited number of different learning pathways**

(Driver 1989; Niedderer, Goldberg, Duit 1992)

Theoretical Approaches

Basic concepts

Basic concepts: "Idea" and "conception"

What is an idea?

- It is a description of the main content of one statement of a student in the researcher's own words.

What is a conception? (mental model, ...)

- ... searching the core of more than one idea
- ... with the most distinctive features of those ideas
- ... with some stability over time
- ... with some stability over contexts
- ... with the aim of data reduction/invariants

"Conception": represented or constructed?

- ... Is constructed by the student in a special context, using more basic "cognitive tools"
- ... not stored as in a big warehouse

Basic concept: learning pathway

- Series of conceptual changes (Dykstra 1992)
- "conceptual pathway" (Scott 1992)
- Describing conceptual evolution over teaching time

Institut für IDP Didaktik der Physik

Basic concept: intermediate conception

- Intermediate notion/conception
  (Driver 1989, Leach et al. 1994)
- Hybrid knowledge (Galili et al. 1993)
- "Synthetic models" (Vosniadou)
- First step in learning (= development)
- In most cases not intended by the teacher
- What can be developed with help (ZPD)
- Often something in between prior conception and intended conception

Basic concept: conceptual profile

- **Parallel conceptions, conceptual ecology**
  (Scott 1992; Hewson 1992; Maloney and Siegler (1993); Tytler (1998); Taber 2000; Petri & Niedderer 1998 and 2003; Hartmann & Niedderer 2005)
  "For years after encountering physics concepts, students may possess not a single coherent understanding but rather a variety of alternative understandings that coexist and compete with one another" (Maloney and Siegler (1993, p. 283).
- **Conceptual profile**
  (Driver et al. 1994; Mortimer 1995, Nieswandt 2002)
  => **Conceptual profile change**

Institut für IDP Didaktik der Physik

Theoretical approaches:
Conceptual change and learning

(5) Need "to examine issues regarding conceptual change"

How to detect/define learning/change?

This is a critical issue:

- Not all examined studies are explicit with that
- For me it is evident that most studies implicitly use a similar understanding and have put great effort in finding those conceptions/ideas which are somehow stable for some time and are applied in different contexts

Learning as evolution of ideas

Givry & Tiberghien (2005)

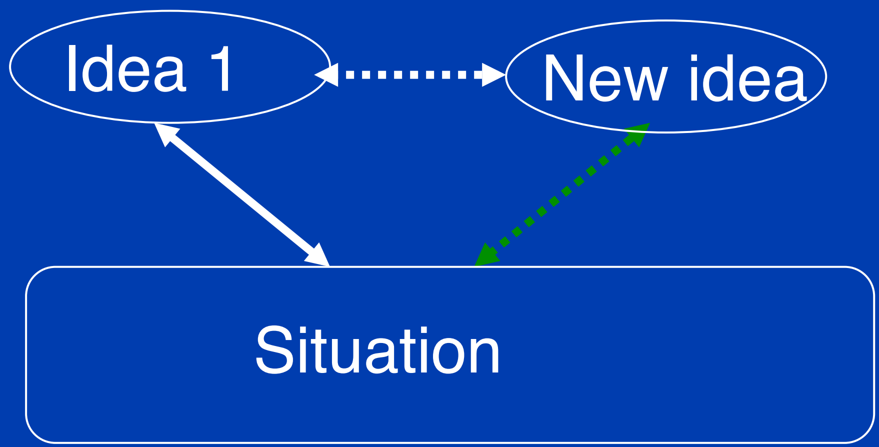
- Expressing a new idea
- Increasing/decreasing the domain of validity of an idea
- Establishing a link between several ideas and developing a network

=> advantage:
learning can be detected more fine-graded

Evolution of ideas - Example Givry (2003)

- Addition of a new idea to a set of ideas

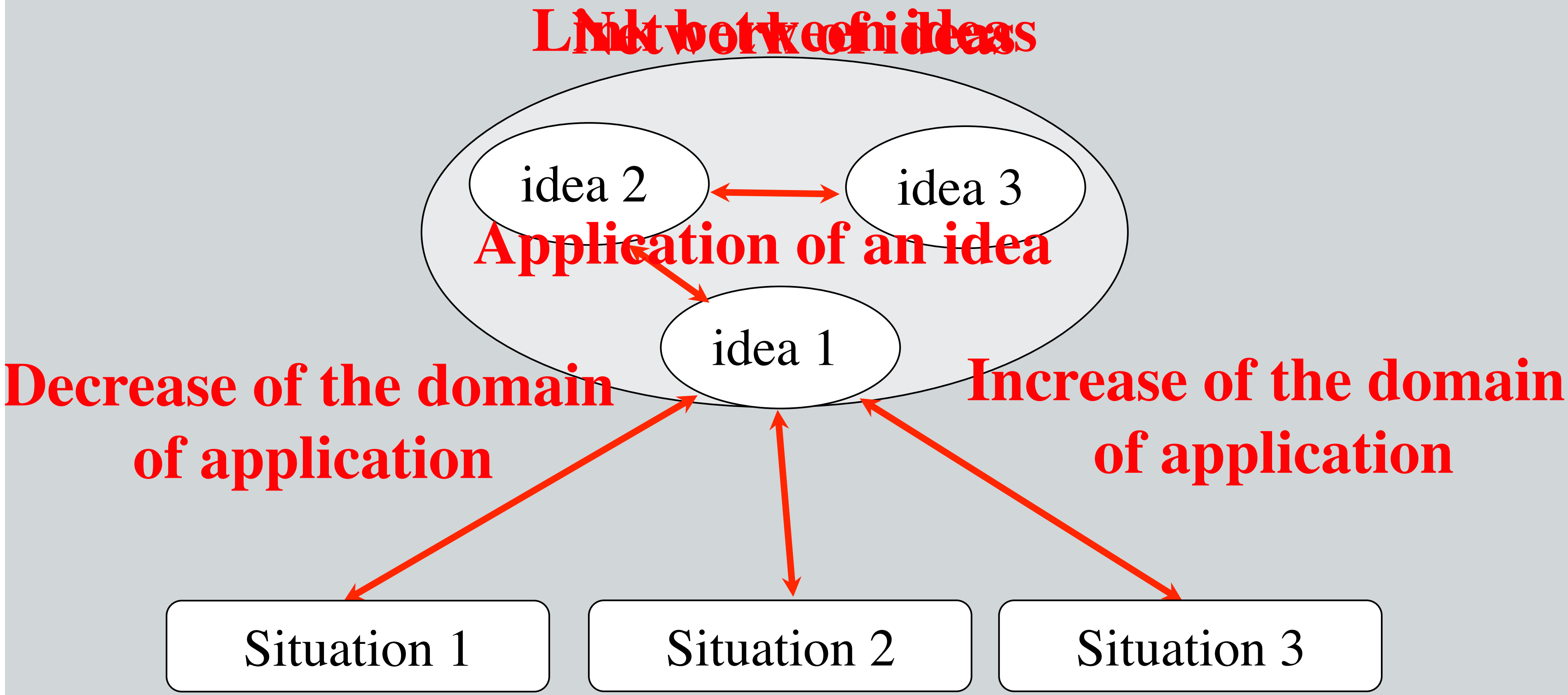
Student weights a balloon and acquire the new idea that air weights



When inflating a tyre, a student can relate idea 1 “quantity of air increases” with the new idea: "number of molecules increases"

Evolution of ideas in terms of links (learning)

Damien Givry 2003



Learning as change of conceptions

- Looking for somewhat stable (meta-stable) conceptions
  - Stable over time: a student constructs the same conception more than once in a meaningful way
  - Stable across different situations: a student constructs the same conception in more than one context in a meaningful way

==> Advantage:

more data reduction, getting the bigger / more important conceptual changes

Methods

(3) Need "to develop research methodologies that would be appropriate for carrying out learning studies".

Methodology - examples

- **Petri & Niedderer 1998**
  - **1 student, 4 months**
  - **About 80 lessons of classroom teaching**
  - **Audio & video partially transcribed, artefacts, interviews**
- **Psillos & Kariotoglu 1999**
  - **3 students, 1 semester, 3 hours per week**
  - **Artefacts, interviews, experimental tasks**
  - **There was continuous audio-recording of the separate groups using three recorders and video-recording of the whole teaching procedure, which was transcribed into written protocols.**
  - **"we present students' reactions to selected episodes throughout the teaching sequence, ..."**

Methodology - examples (ctd.)

- **Taber 2001**
  - "longitudinal interview-based study ... Tajinder was interviewed on 23 occasions over his two-year course"
  - 1 student Taijinder, 2 years
  - 23 interviews
- **Clement & Steinberg 2002**
  - "The data base for this article is a set of tutoring interviews with a student whom we shall call Susan who was 16 years old ..."
  - 1 student Susan, 2 weeks, 5 sessions
  - "think aloud" method

Methods used

	Number of students/ Time	Data 1 Interview etc.	Data 2 Audio/Video of teaching	Content focus
Petri& Niedderer	1 student 4 months, 6 h p. w.	Artefacts, interviews, tasks	audio video transcript	Quantum atomic model
Psillos & Kariotoglu	3 students 1 semester, 3 h p. w.	Artefacts, interviews, exp. tasks	audio video transcript	Force and pressure in fluids
Taber	1 student 2 years	23 interviews	-	Chemical bonding
Clement & Steinberg	1 student 2 weeks, 5 sessions	5 tutoring interviews	5 tutoring interviews	Electrical current and voltage

Didaktik der Physik

Methodology - discussion

- All studies followed single students

"Attempts to track learning processes at this level of detail in groups of students have been frustrating for us because we do not hear enough from each student to follow the process without large gaps."

" ... such studies can be an important source for generating grounded hypotheses about learning processes that have a substantial initial level of plausibility and that are worth investigating in larger samples."
(Clement & Steinberg 2002)

Selected Results

Results about "Learning pathways"

Need 1:"to document learning pathways ..."

Institut für IDP Didaktik der Physik

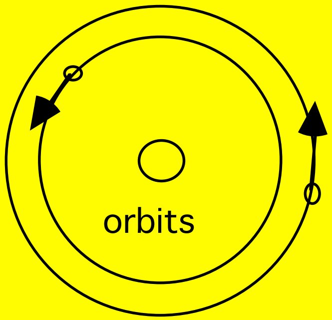
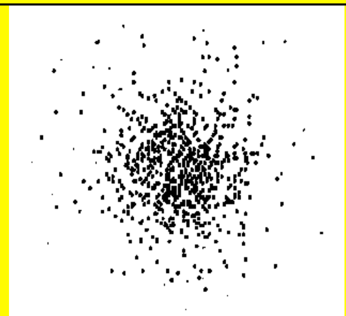
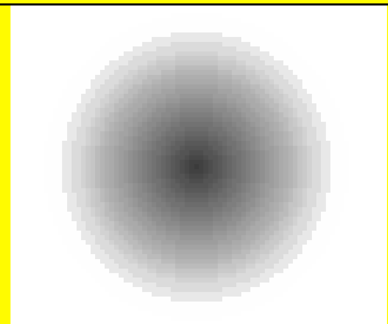
Learning as change of conceptions

- **Petri & Niedderer 1998**
  "Carl's learning pathway is described as a **sequence** of several **meta-stable conceptions** of the atom, …"
- **Psillos & Kariotoglu 1999**

  "Based on classroom monitoring and the post teaching interviews we suggest that the **detected conceptions** were **stable products** which were employed by certain students in order to make sense of **several experimental situations** during teaching."
- **Taber 2001**
  "Learning has been defined by Petri and Niedderer (1998: 1075) as 'a change in a cognitive system's **stable** elements'."
- **Clement & Steinberg 2002**
  Multiple sources of evidence from different lines of the transcript were sought to provide triangulated support for our final models wherever possible.

Results about "Learning pathways"

A "learning pathway" in atomic physics

Carl's first conception of the atom	Carl's second conception of the atom	Carl's third conception of the atom	Carl's fourth conception of the atom
 The planetary model	 The probability orbit model	 The state-electron model	 The electron cloud model

After Petri & Niedderer (1998)

Results about "Learning pathways"

"In figure 1 we illustrate the intended initial and scientific conceptions as well as the additionally detected refined initial and refined scientific conceptions in an ideal sequential order."

Initial concept for P/F	Refined initial concept for P/F	Scientific concept for P/F	Refined scientific concept for P/F
Force = pressure "pressure-force model"	Force ≈ pressure, pressure as a state variable, force as interaction	Force ≠ pressure, P = F/A (qualitative)	Force ≠ pressure, P = F/A (qualitative) Understanding additivity

After Psillos & Kariotoglu 1999

Institut für IDP Didaktik der Physik

Results about "Learning pathways"

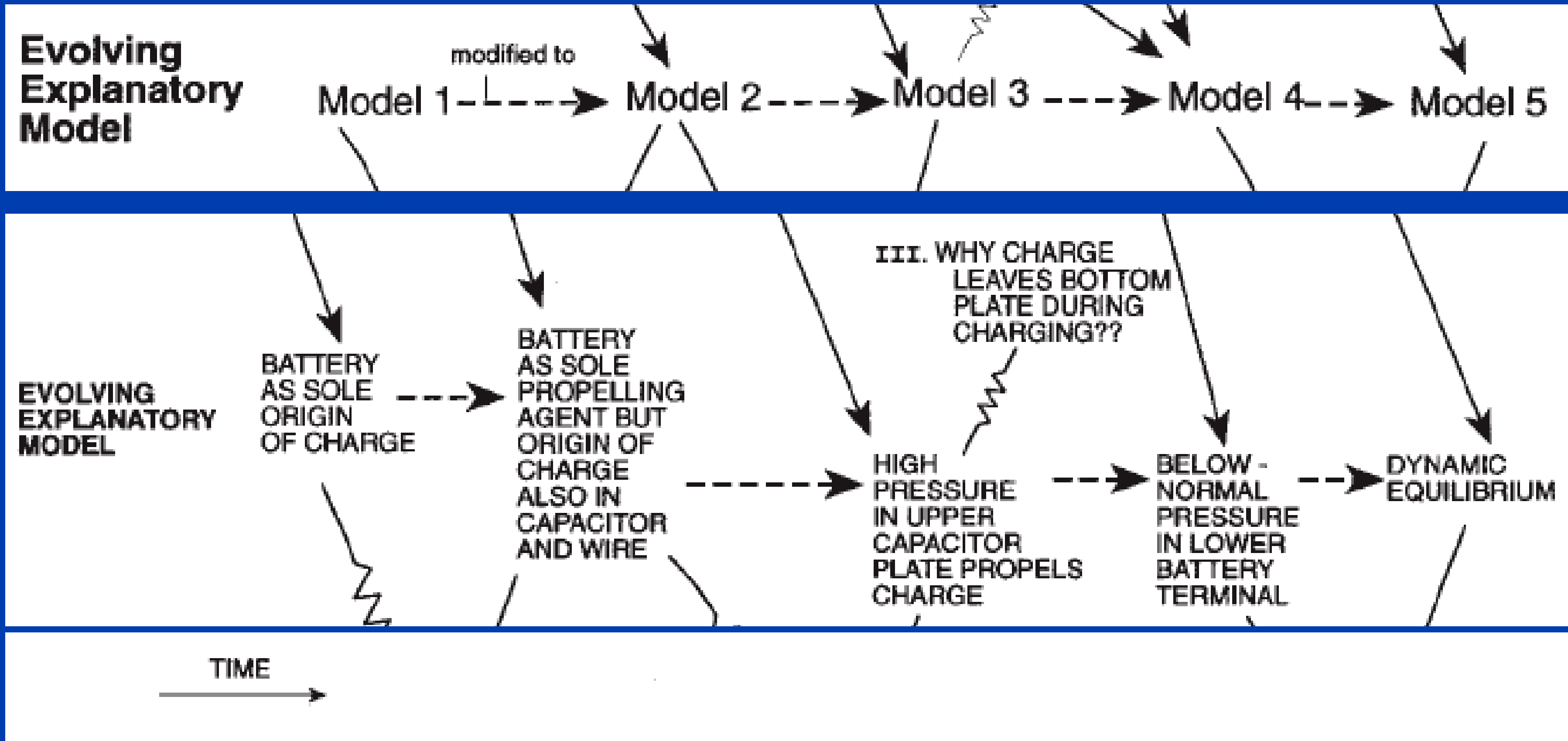
"The main features of Tajinder's developing understanding of chemical bonding may be summarized."

Principle in explaining chemical bonding at beginning of course	Second explanatory principle additionally applied later in the course	Third explanatory principle additionally applied later in the course
The octet rule explanatory principle	**The minimum energy explanatory principle**	**The Coulombic forces explanatory principle**
• atoms are stable if they have full outer shells; • an atom that is unstable will want to become stable; • the unstable atom will form bonds such ...	• configurations of physical systems can be ascribed an energy level; • lower energy is more stable than higher energy; • physical systems will evolve towards lower energy configurations.	• there is always a force between two charged particles; • ... • the magnitude of the force diminishes with increased charge separation; • forces acting on particles may be balanced at equilibrium.

After Taber 2001

Results about "Learning pathways"

"Evolving Explanatary Models"



Clement & Steinberg 2002

Results about "Intermediate conceptions"

Institut für IDP Didaktik der Physik

Results about "Intermediate conceptions"

- **Psillos&Kariotoglu 1999**

  "student teachers' actual constructions in the course of teaching revealed unexpected intermediate steps"

  "An important indication from the data shows that an intermediate, refined, initial conception was constructed too, ..."

- **Taber 2001**

  "According to Driver (Driver 1989, Leach et al. 1994), the building of bridges between children's science and formal science may involve 'intermediate notions' or 'intermediate conceptions', ..."

- **Clement & Steinberg 2002**

  "intermediate explanatory models utilizing dynamic imagery are the form of her new conceptual understanding"

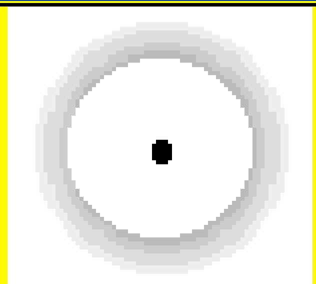
Results about "Intermediate conceptions"

Different examples of intermediate conceptions combining

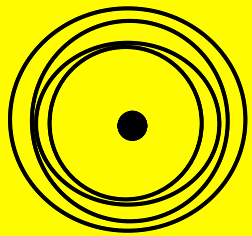
- **a (classical) particle view with**
- **some first ideas of quantum physics**

to be seen as some kind of assimilation.

a wave orbit



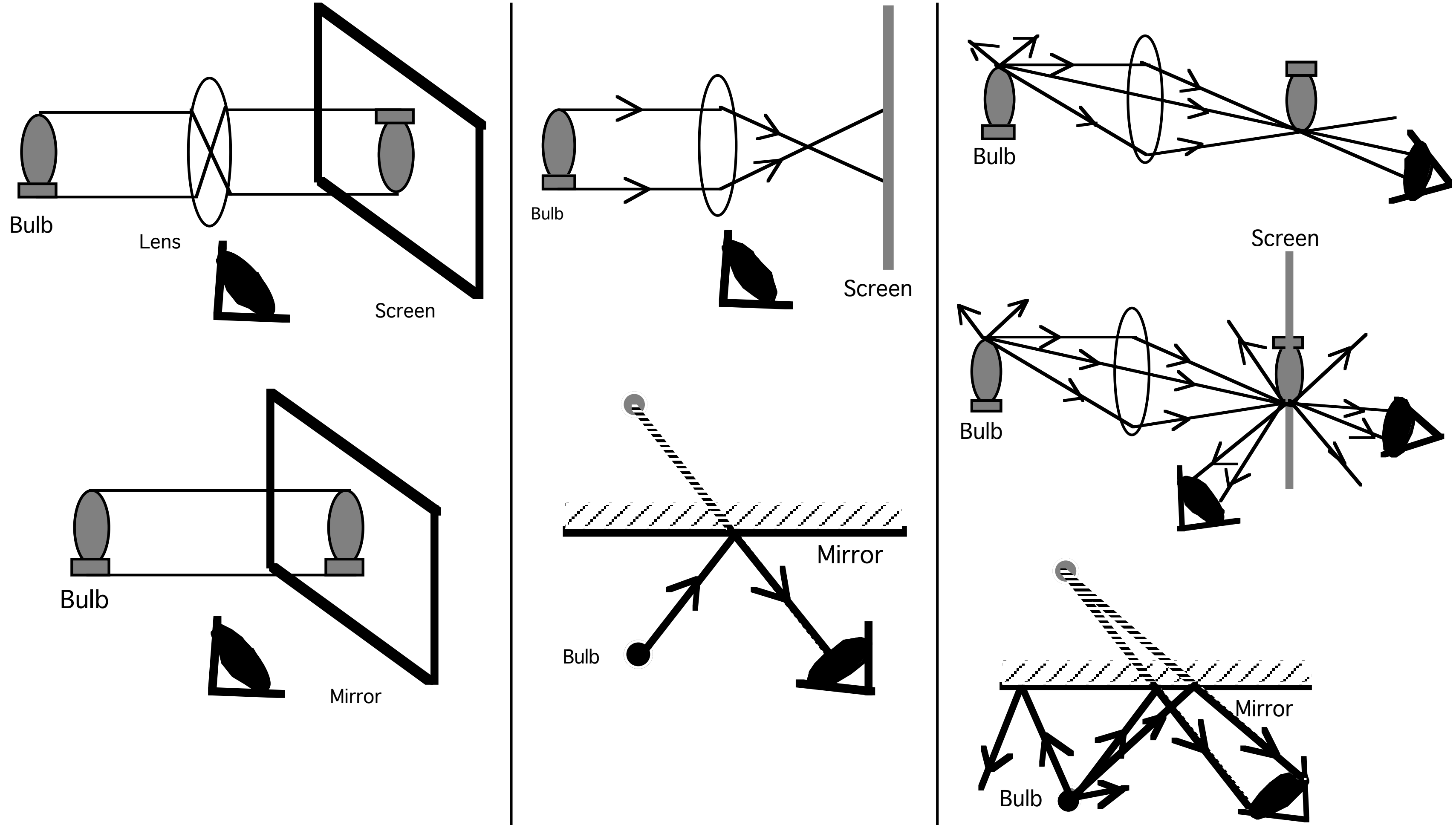
a smeared orbit



a sample of neighbour orbits with high probability

Petri & Niedderer (1998)

Intermediate conception as final learning result
(“Hybrid knowledge”) (Galili, Bendall & Goldberg 1993)



Pre-Instruction:
Holistic diagram

Post-Instruction:
Relevant ray diagram

Formal Physics:
Standard ray diagram

Results about "conceptual profile"

(4) Need

"to document changes in student's conceptual ecology".

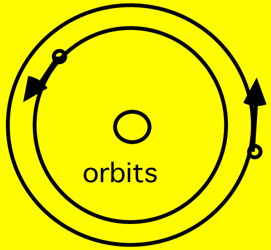
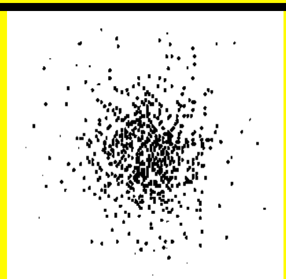
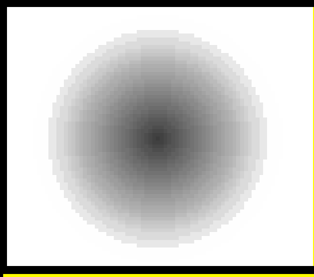
Results about "conceptual profile"

Taber 2001

"Various theorists have described how an individual's understanding of a concept may be multifaceted; **how conceptual frameworks develop in a cognitive ecology**, and are subject to selection pressures; and how alternative frameworks compete in terms of their explanatory coherence. The present paper applies these ideas to a case study of learning in science. It is argued that conceptual development may be described in terms of a gradual shift in which of several alternative explanatory principles is the learners' preferred choice."

Results about "conceptual profile"

Final state of Carl ‘s cognitive system “atom"

Layer		Strength	Status
Planetary model		high	low
Probability model		middle	middle
Electron cloud model		middle	high

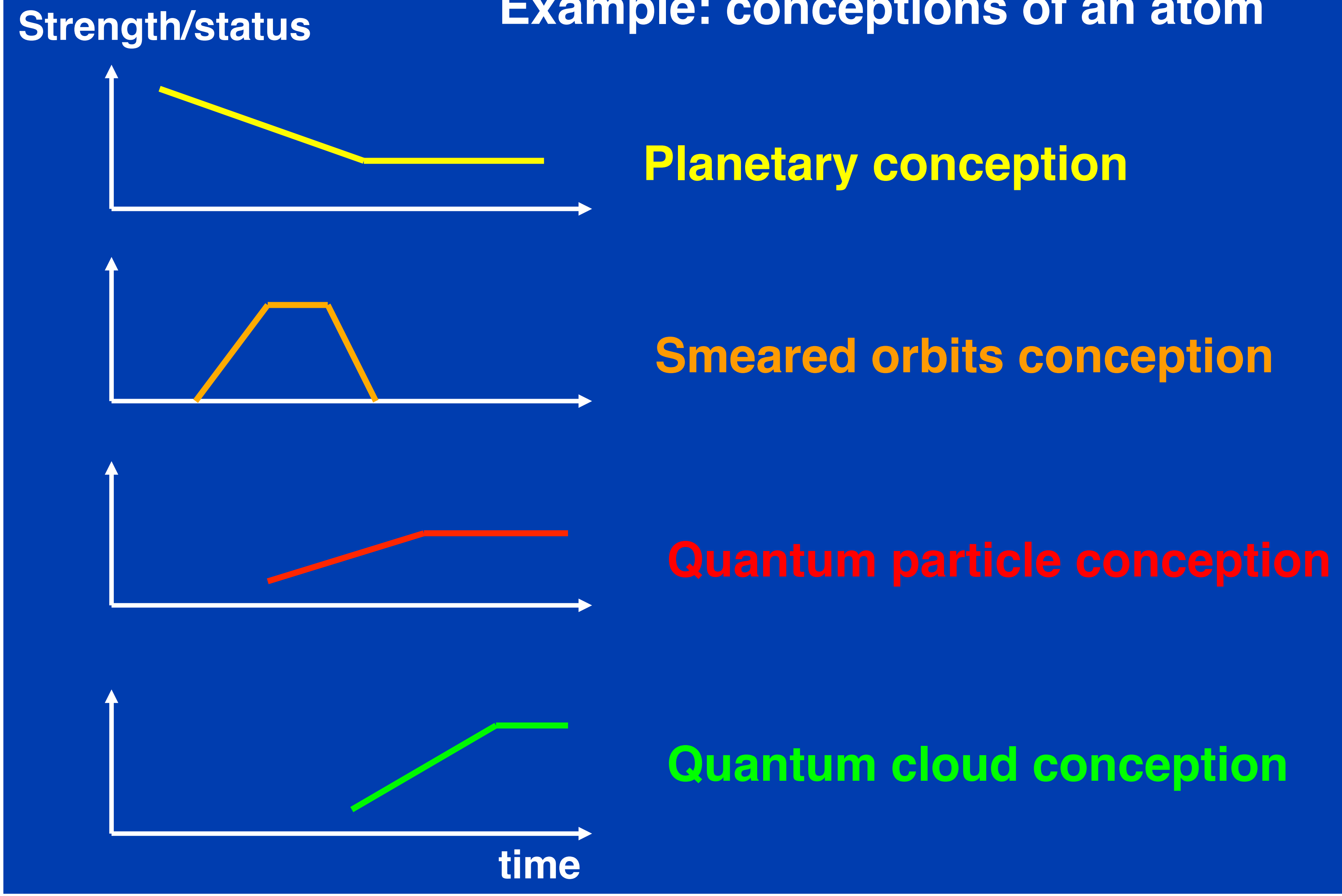
Petri& Niedderer 1998

Institut für IDP Didaktik der Physik

An example of conceptual profile change

- A reconstruction based on data

Example: conceptions of an atom



Learning Effects
from the Learning Environment

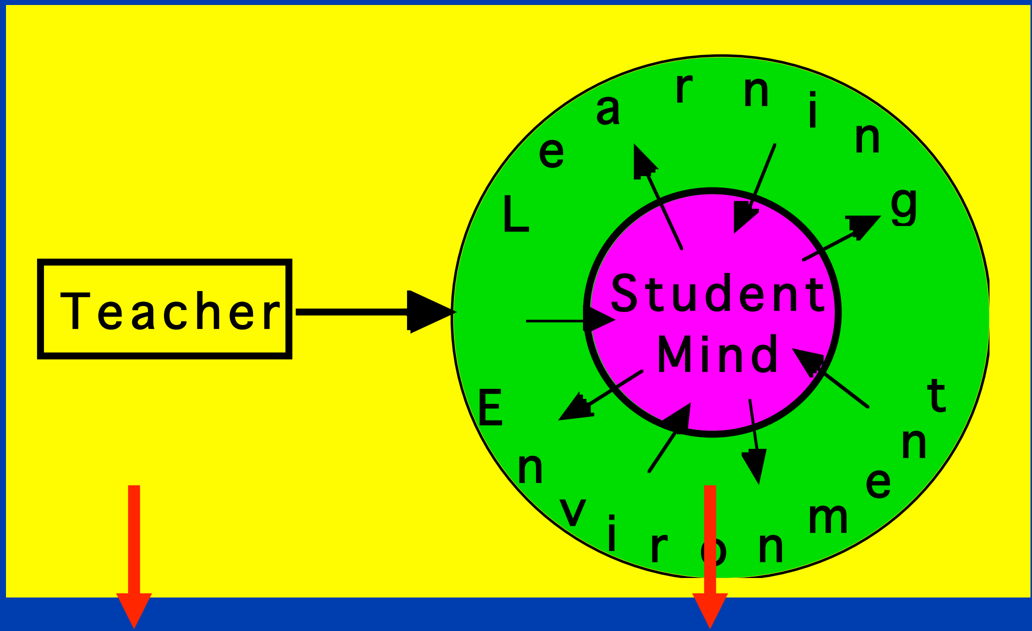
Doctoral Dissertation of Marion Budde (2004)

Budde, M. (2004). ***Lernwirkungen in der Quanten-Atom-Physik. Fallstudien über Resonanzen zwischen Lernangeboten und SchülerInnen-Vorstellungen.***

(Learning effects in quantum atomic physics – case studies on resonances between content-specific elements of the learning environment and the evolution of students' conceptions).

Institut für IDP Didaktik der Physik

Constructivist view of learning



Teacher's intented conceptions

Student's own constructions "intermediate conceptions"

The idea of resonance (Glasersfeld 1992)

Learning environment

- teacher's statements
- other students' statements
- textbook

Learning effects as resonance →

Learning steps of a single student as conceptual evolution

Learning environment

Resonance

Cognitive system of student

General hypothesis

Depending on the individual cognitive system of a student, different parts of the learning environment show a higher or lower learning effect.

Categories of resonance - overview

Aspect "content"
- Congruent resonance
- Disgruent resonance
- No resonance

Aspect "evaluation"
- Intended resonance
- Semi-intended
- Not intended

Aspect "strength"
- Strong resonance
- Weak resonance

Symbolic arrows

Congruent, intended, strong, direct, resonance

Disgruent, intended, strong, direct, resonance

Congruent, **not intended**, strong, direct, resonance

Congruent, intended, **weak**, direct, resonance

Example of results (electronium-cloud)

Learning environment — **Cognitive system of student**

Electronium=cloud → Electronium=cloud

Direct, intended, congruent, strong resonance

Electronium=liquid → Electronium=liquid

Delayed, intended, congruent, strong resonance

Electronium is NOT a liquid ↛ Electronium=liquid

Two final teaching-learning hypotheses

- The introduction of an "electronium" model of the atom increases the chance that students accept a quantum description of the atom, based on the Schrödinger equation.
- The notion of a continuous electron ("electronium") fosters a the development of a conception of the atom, in which electrons do not move in stable states.

==> The electronium model can be seen as a positive "stepping stone" (Clement 1992)

Aims

Aim of learning process studies: PCK

Basic:

- Understand better teaching and learning

Applied:

- Adapt teaching aims to what seems learnable (Tiberghien 1997)
- Help teachers to be aware that students construct their own conceptions, which are normally different from teacher's intentions.
- Make teachers aware that those intermediate conceptions might be important as stepping stones (Brown & Clement 1992; Driver, Leach et al. 1994; Petri & Niedderer 1998; Psillos & Kariotoglu 1999; Taber 2001)
- Determining learning effects of special elements of the learning environment and thus helping to improve the learning environment by curriculum development. (Budde 2004, 2005)

Current work in my group in Sweden

3 learning process studies

Three new learning process studies in Sweden

- **Roger Andersson**
  Geometrical optics with computer software (F. Goldberg) and constructivist teaching strategy
- **Susanne Engström**
  Physics of sustainable energy systems
- **Tor Nilsson**
  Chemical thermodynamics at university level

Important methodological issues

- Which data from tests, interviews, video and audiotapes, artefacts, etc.
- Combinations of quantitative data from all students (tests) and qualitative data from three single students can be feasible and give best results?
- How to work in content areas, where not much is known about alternative conceptions?

Process of finding conceptions

- Intended knowledge: scientific conceptions (= concepts)
- Prior (everyday) conceptions
  - Literature, e.g. Duit 2006
  - Useful to get ideas: conceptions from historical development

  Sometimes the area is new, no or little research results about prior conceptions available.
- First step: analysing students' statements from the point of view of intended conceptions ==> right or wrong
- Second step: finding an explanation, why students made this mistake ==> hypothetical formulation of a conception
- Third step: looking for more evidence, looking for stability, reformulating the conception

Institut für IDP Didaktik der Physik

References

Brown, D.E., Clement, J. (1992). Classroom teaching experiments in mechanics. In: Duit, R., Goldberg, F., Niedderer, H.: *Research in physics learning: Theoretical issues and empirical studies.* Kiel: IPN, 380-397

Budde, M. (2004). *Lernwirkungen in der Quanten-Atom-Physik. Fallstudien über Resonanzen zwischen Lernangeboten und SchülerInnen-Vorstellungen. (Learning effects in quantum atomic physics – case studies on resonances between content-specific elements of the learning environment and the evolution of students' conceptions).* Doctoral dissertation University of Bremen. In H. Niedderer, H. Fischler (eds): Studien zum Physiklernen, Band 31. Berlin: Logos

Budde, M., Niedderer, H., Scott, P., Leach, J. (2002). The quantum atomic model 'Electronium': a successful teaching tool. *Physics Education*, 37, 204-210

Clement , J. J., Steinberg, M. S. (2002). Step-Wise Evolution of Mental Models of Electric Circuits: A “Learning-Aloud” Case Study. *The Journal of the Learning Sciences* 11(4), 389–452

Duit, R. (2006). Bibliography – STCSE. Students’ and Teachers’ Conceptions and Science Education1. Kiel: IPN. See http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html

Duit, R., Goldberg, F., Niedderer, H. Eds. (1992). *Research in Physics Learning - Theoretical Issues and Empirical Studies*. Kiel: IPN

Duval R. (1995). *Sémiosis et pensée humaine, registres sémiotiques et apprentissages intellectuels.* Ed Peter Lang.

Dykstra, D. (1992). Studying conceptual change: Constructing new understandings. In R. Duit, F. Goldberg, H. Niedderer (eds.): *Research in Physics Learning - Theoretical Issues and Empirical Studies*. Kiel: IPN, 40-58

References

Galili, I., Bendall, S., Goldberg, F.M. (1993). The effects of prior knowledge and instruction on understanding image formation. *Journal of Research in Science Teaching* 30, 3, 271-301

Givry, D. (2003). *Étude de l'évolution des idées des élèves de seconde durant une séquence d'enseignement sur les gaz*. (Study of the evolution of students' knowledge during a teaching sequence on gases at the upper secondary school level). Doctoral dissertation, Université Lyon II.

Givry, D. & Roth, W.-M. (in press). Toward a New Idea of Conceptions and Conceptual Change: The Interplay of Talk, Gestures, and Semiotic Resources in the Setting. *Journal of Research in Science Teaching*.

Givry, D., Tiberghien, A. (2005). Studying the evolution of student's ideas in a physics classroom. In: Niedderer, H., Asikainen, M., Budde, M., Givry, D., Psillos, D., Tiberghien, A.: Learning process studies. In: R. Pintò & D. Couso (Eds.), Proceedings of the fifth international ESERA conference on Contributions of Research to Enhancing Students' Interest in Learning Science, CD, Barcelona, Spain (2005), 451-463

Hartmann, S., Niedderer, H. : Parallel Conceptions and Learning in the Domain of Force and Motion. In: K. Boersma, M. Goedhart, O. de Jong, H. Eijkelhof (Eds.): Research and the Quality of Education, Dordrecht: Springer (2005), 471 - 482

McDermott, L. C. (1991). Millikan lecture 1990: What we teach and what is learned: Closing the gap. *American Journal of Physics* 59(4): 301-315

Niedderer, H., Goldberg, F., Duit, R. (1992). Towards learning process studies: A review of the workshop on research in physics learning. In R. Duit, F. Goldberg, H. Niedderer (eds.): *Research in Physics Learning - Theoretical Issues and Empirical Studies*. Kiel: IPN, 10-28
Found 2006 at http://www.idn.uni-bremen.de/

Niedderer, H. (2001): Physics Learning as Cognitive Development. In: Evans, R. H.; Andersen, A. M.; Sørensen, H. (eds.), *Bridging Research Methodology and Research Aims*. Student and Faculty Contributions from the 5th ESERA Summerschool in Gilleleje, Denmark. The Danish University of Education, 397-414.
Found 2006 at http://www.idn.uni-bremen.de/

References

Petri, J., and Niedderer, H. (1998). A learning pathway in high-school level quantum atomic physics. *International Journal of Science Education*, 20 (9), 1075-1088.

Petri, J., Niedderer, H. (2003). Atomic Physics in Upper Secondary School: Layers of Conceptions in Individual Cognitive Structure. In: Psillos, D., Kariotoglou, P., Tselfes, V., Hatzikraniotis, E., Fassoulopoulos, G., Kallery, M., (eds.): *Science Education in the Knowledge-Based Society*. Dordrecht: Kluwer Academic Publishers 137-144

Psillos, D., Kariotoglou, P. (1999). Teaching fluids: Intended knowledge and students´ actual conceptual evolution. *International Journal of Science Education* 21(1): 17-38

Reif, F., Larkin, J. H.: Cognition in Scientific and Everyday Domains: Comparison and Learning Implications, JRST Vol.28, NO. 9, PP. 733-760 (1991)

Scott, P.H. (1992). Pathways in learning science: A case study of the development of one student's ideas relating to the structure of matter. In: Duit, R., Goldberg, F., Niedderer, H.: Research in physics learning: Theoretical issues and empirical studies. Kiel: IPN, 203-224

Taber, K. S. (2000). Multiple frameworks?: Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education*, VOL. 22, NO. 4, 399 - 417

Taber, K. S. (2001). Shifting sands: A case study of conceptual development as competition between alternative conceptions. *International Journal of Science Education*, 23(7), 731-754.

Tiberghien, A.(1997). Learning and teaching: Differenciation and Relation. *Research in Science Education*, 27(3), 359-382

Tiberghien, A. (2000). Designing teaching situations in the secondary school. In R. Millar, J. Leach and J. Osborne (Editors): *Improving science education: the contribution of research.* Buckingham, UK: Open University Press. 27-47

von Glasersfeld, E. (1992): A Constructivist View of Learning and Teaching. In R. Duit, F. Goldberg, H. Niedderer (Eds.): *Research in Physics Learning: Theoretical Issues and Empirical Studies*. Proceedings of an International Workshop in Bremen, Kiel: IPN, 29-39.

Scott 1992; Hewson 1992; Maloney and Siegler (1993); Tytler (1998); Taber 2000; Petri & Niedderer 1998 and 2003; Hartmann & Niedderer 2005)