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

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Introduction

- 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".
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Defining "learning process studies"

- Data from "during" learning
- Related to some form of conceptual change
  ... building on the most successful research line in science education: alternative conceptions (Duit 2006)
- Similar to longitudinal studies?
Four, more recent examples of learning process studies


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

Transmissive Instruction

Teacher → Information → Student

Constructivist Instruction

Learning
Environment

Teacher's intended conceptions

Student's own constructions
"intermediate conceptions"
Theoretical Approaches

Basic statements/assumptions
Learning science means always conceptual change ... ...

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

<table>
<thead>
<tr>
<th>The conception &quot;smeared orbits model of the atom&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propositional representation</td>
</tr>
<tr>
<td>Image representation</td>
</tr>
</tbody>
</table>

Found by different authors, with different teaching approaches: Bayer 1985, Bethge 1988, Petri 1996
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
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
Parallel conceptions, conceptual ecology
“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
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

- Addition of a new idea to a set of ideas

New idea

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

Situation

Idea 1

New idea

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

Network of ideas

Application of an idea

Decrease of the domain of application

Increase of the domain of application

Situation 1

Situation 2

Situation 3
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
(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

<table>
<thead>
<tr>
<th>Data 1</th>
<th>Data 2</th>
<th>Content focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artefacts, interviews, tasks</td>
<td>Audio video transcript</td>
<td>Quantum atomic model</td>
</tr>
<tr>
<td>Artefacts, interviews, exp. tasks</td>
<td>Audio video transcript</td>
<td>Force and pressure in fluids</td>
</tr>
<tr>
<td>23 interviews</td>
<td>-</td>
<td>Chemical bonding</td>
</tr>
<tr>
<td>5 tutoring interviews</td>
<td>5 tutoring interviews</td>
<td>Electrical current and voltage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of students/ Time</th>
<th>Data 1 Interview etc.</th>
<th>Data 2 Audio/Video of teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petri &amp; Niedderer</td>
<td>1 student</td>
<td>4 months, 6 h p. w.</td>
</tr>
<tr>
<td>Psillos &amp; Kariotoglu</td>
<td>3 students</td>
<td>1 semester, 3 h p. w.</td>
</tr>
<tr>
<td>Taber</td>
<td>1 student</td>
<td>2 years</td>
</tr>
<tr>
<td>Clement &amp; Steinberg</td>
<td>1 student</td>
<td>2 weeks, 5 sessions</td>
</tr>
</tbody>
</table>
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 …"
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’."
Results about "Learning pathways"

A "learning pathway" in atomic physics

<table>
<thead>
<tr>
<th>Carl's first conception of the atom</th>
<th>Carl's second conception of the atom</th>
<th>Carl's third conception of the atom</th>
<th>Carl's fourth conception of the atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>The planetary model</td>
<td>The probability orbit model</td>
<td>The state-electron model</td>
<td>The electron cloud model</td>
</tr>
<tr>
<td>Orbits</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After Petri & Niedderer (1998)
"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."

<table>
<thead>
<tr>
<th>Initial concept for P/F</th>
<th>Refined initial concept for P/F</th>
<th>Scientific concept for P/F</th>
<th>Refined scientific concept for P/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force = pressure &quot;pressure-force model&quot;</td>
<td>Force ≈ pressure, pressure as a state variable, force as interaction</td>
<td>Force ≠ pressure, P = F/A (qualitative)</td>
<td>Force ≠ pressure, P = F/A (qualitative) Understanding additivity</td>
</tr>
</tbody>
</table>

After Psillos & Kariotoglu 1999
"The main features of Tajinder’s developing understanding of chemical bonding may be summarized."

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

After Taber 2001
Results about "Learning pathways"

"Evolving Explanatory Models"

Clement & Steinberg 2002
Results about "Intermediate conceptions"
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"
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.

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".
"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”

<table>
<thead>
<tr>
<th>Layer</th>
<th>Strength</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planetary model orbits</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Probability model</td>
<td>middle</td>
<td>middle</td>
</tr>
<tr>
<td>Electron cloud model</td>
<td>middle</td>
<td>high</td>
</tr>
</tbody>
</table>

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Petri & Niedderer 1998
An example of conceptual profile change
- A reconstruction based on data

Example: conceptions of an atom

- **Planetary conception**
- **Smeared orbits conception**
- **Quantum particle conception**
- **Quantum cloud conception**
Learning Effects from the Learning Environment

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

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**

- **Electronium=cloud**
  - Direct, intended, congruent, strong resonance

- **Electronium=liquid**
  - Delayed, intended, congruent, strong resonance

**Cognitive system of student**

- **Electronium=cloud**
- **Electronium=liquid**

Electronium is NOT a 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 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


References


References


