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ABSTRACT

Over the past 10 years, numerous empirical investigations of learning in physics have been carried out at the Institute of Physics Education (IPE) at the University of Bremen in Germany. The objectives of these investigations were: (1) to describe in detail individual learning processes; (2) to construct theoretical principles of individual learning processes at different age levels; and (3) to test curriculum based on the work of the first two objectives. The studies were grounded in a situated cognition framework. According to situated cognition theory, knowledge is ultimately grounded in each individual's actions with the material and the social world. On the basis of empirical studies at several age levels, a detailed framework that includes operationalizations for levels of situated learning was developed. This framework allows for quantification of certain aspects of the development of situated cognition in terms of complexity. It provides perspectives for a better understanding of learning and teaching processes and an improvement in curriculum design. Contains 42 references. (Author/PVD)

Learning Processes in the Field of Electricity: Results of a Cross Age Study

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Abstract

Over past 10 years, numerous empirical investigations of learning in physics have been carried out at the Institute of Physics Education (IPE). The objectives of these investigations were to (a) describe in detail individual learning processes, (b) to construct theoretical principles of individual learning processes at different age levels and (c) to test curriculum based on our work in (a) and (b). The studies were grounded in a situated cognition framework. According to situated cognition, knowledge is ultimately grounded in each individual's actions with the material and the social world. On the basis of empirical studies at several age levels, we developed a detailed framework that includes operationalizations for levels of situated learning. This framework allows us to quantify certain aspects of the development of situated cognition in terms of complexity. It provides perspectives for a better understanding of learning and teaching processes and an improvement of curriculum design.

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INTRODUCTION

Over the past decades more and more scientists who deal with teaching and learning devoted themselves to the question how to initiate and support students' thinking and learning *processes*. Many investigations are concerned with complex relationships between individual behavior and social interaction in the classroom. The starting point of these projects was to understand the use of students' concepts before physics lessons (mostly described as "prior knowledge" or "preunderstanding" in a certain domain) (Driver et al, 1994; Pfundt & Duit, 1994). These investigations can be described as an inquiry of pre-instructional conditions. One of the main results of these investigations was that students have special intuitions and conceptual frameworks related to physical phenomena. Students' pre-instructional understandings play an important role when students have to learn science. Intuitions postulate an individual structure of students' frameworks or knowledge and in contrast to this a structure of the sciences, which are made by experts. Many investigations were conducted about misconceptions and the need of directed conceptual change during learning processes with student oriented aims of investigations (Duit, 1991, 1993, 1996; Dykstra, 1992; Fischer & Breuer, 1994; Hewson, 1984, 1989; Schwedes & Schmidt, 1991; Scott, Asoko & Driver, 1991; Vosniadou, 1994). Main intent was to try out possibilities of organizing conceptual change during learning - e.g. the use of special teaching strategies (e.g. bridging strategies (Brown & Clement, 1987, 1991) and analogies (Duit, 1991, 1996; Schwedes, 1995.) - in the case that the students have prior knowledge according to the publications described above.

As a result of these investigations, students came into the focus of research. This is an important fact, because the individual conditions and experiences have an important influence on learning processes. From investigations such as those cited above, we know what the majority of the students in several age groups know - in constructivist terms: what they are able to construct - about different physics topics such as electric circuits, motion, optics, etc..

On the basis of this knowledge teaching strategies were designed (Brown, Clement, 1987, 1991; Désautel & Larochelle, 1990, 1991; Driver et al., 1994; Duit, 1993; Niedderer, 1987, 1992; Osborn, 1991). Empirical investigations of the effects of these teaching strategies were often done using tests and interviews before, during and after a teaching period. But there exist problems of individual differences between students learning under the same classroom conditions and the dynamic of individual processes which are not explained (Edwards, 1993; Roth, 1993, 1996). The effects of instructions are not the same for all students. This leads us to the following questions: How does learning take place? What are the individual processes of learning? How can they be described? Which are the "right" conditions for learning physics? How can interactions be organized in the classroom? These questions devoted to individual processes, their dynamic during learning physics and their description were and still are in the focus of our investigations.

An increasing number of investigations aims at describing learning pathways step by step. These investigations for examples describe learning processes by means of change in the concepts used (Lichtfeldt, 1991) or intermediate states (Niedderer, 1994; Petri, 1996). Roth (1995, 1996) described investigations which focus on social aspects in learning situations. Classroom situations are analyzed before the beginning of the next lesson and interactions are designed on the basis of the results of the previous lesson. Lijnse (1995, 193) stated that: "'developmental research' is needed in which small-scale curriculum development is cyclically coupled to in depth classroom research of teaching-learning processes".

A new focus of our work is to try to develop a method to study and describe learning processes only by the analysis of students' behavior recorded on videotape. On the basis of teaching in actual classroom lessons we developed a constructivist learning theory (grounded on a perspective e.g. described by Brooks [1995], Clancey [1993], Chapman [1991]and others) to describe individual learning processes and methods, investigate and analyze them without disturbing the learning/teaching processes. We conducted all our investigations in the field of electricity with several age groups (grade 5 to second year of university).

Having observed students learning electricity in several age groups during the past 10 years, we have had many empirical experiences in studying and describing learning processes in qualitative and quantitative ways (Prüm, 1988; Fischer, 1989, 1991, 1992; Aufschnaiter, 1992; Welzel, 1995a,b, 1996; Breuer, 1995; Seibel, 1995; Langensiepen, 1996). The objectives of these investigations were

1. to develop a theoretical framework to describe learning processes in detail and to find basic principles or rules about the dynamics of individual pathways and the influences on individual learning pathways.
2. to develop and prove a useful methodology to study these processes on usual learning environments at school.

Learning processes seen as an individual development to a level of higher complexity of acting in similar contexts are in the focus of our research interests.

Situated cognition

We use the term "situated cognition" in the way described by Clancey (1993), Roth (1995), and Lijnse (1995). We think, that in every *new* situation *new* ideas are produced in a context dependent way - in a frame of situated cognition. These ideas are generated in the context of the interaction with the learning material and social environment.

If we follow students' "ideas" in a classroom context, we find a development, e.g. a process of further developed ideas related to the context, activities, and meaning. We describe this as situated dependent processes of constructing meanings in a specific situation.

What is the dynamics of situated cognition development? Analyzing our data we found an increase of complexity of cognition. This is illustrated by way of an example.

During their activities in a new context of a physics course, the students pass through two periods of development: (a) At the first stage the students get to know and to describe electrostatics and electric phenomena. (b) At the second stage they treat and explain these phenomena in different relationships.

During the first period they act with new **objects** within this new context "electrostatic". E.g. with plastic films (transparencies), metal plates, glow lamps, different rods, an electroscope and others. Acting with the objects (**focusing** on details and **operating** with the objects within the context) they get distinguishing features, which are relevant in the new context. Some of these features become **properties** of a whole class of objects of the context. E.g. chargeable, not chargeable, conducting. Students construct relationships among stable properties to form **events**: a glow lamp is glowing, if you touch it with a charged plastic film or the pointer of the electroscope turns, if the electroscope is touched by a charged object. If the students move in period (b) they connect systematically several properties (at least one has to be variable) and design **programs** in this way. These programs are tested out and proved in other and/or different contexts. E.g. a glow lamp will be used as a tester for charge in different experiments or an electroscope will be charged by "influence and earth". Subsequently they construct **principles**, that is covariation of variable properties for classes of contexts. These are principles based on individual experiences with programs, e.g.: every time you reduce the size of the roller blind area, the density of charge on it increases. The next higher level can be described as connecting principles - at first spontaneous (connections) and then systematically (networks). **Systems** are produced.

If we use these levels as heuristic in data analysis, we observe that students act in more and more complex ways, within their physics environment. The students become able to construct more complex ideas or to realize situated cognition more complex. But this development depends on individual experiences in similar contexts and depends on actual interactions.

So we obtain a hierarchy of levels of complexity such as shown in figure 1. We use these levels as a quantitative criterion to describe the complexity of student's ideas (or situated cognition):

systems
- networks
- connections

principles
- programs
- events

properties
- operating
- focusing

objects

↑ increase of complexity

Figure 1 Levels of complexity

Following the reconstructed ideas according to the context, every idea can be related to a level of complexity. Also can be found, which ideas are produced as a further development of the predecessors.

If we want to say something about learning processes on the basis of situated cognition, we have to follow the changes of development of situated cognition across several similar contexts. We therefore gathered our data over long periods of time. We than look for nearly similar contexts and analyzed the development of students ideas. We find characteristic changes when we compare the development of situated cognition for the same student in these contexts.

CONTEXT OF STUDY

Exemplifying the methodology of our empirical case studies we now present one method of them in more detail.

During 1992 Welzel taught a physics course about electricity (electrostatics/electric circuits) to grade 10 students in Bremen, Germany. The duration of this course was 15 weeks (two lessons, 45 minutes each, per week). The main objective of this investigation was to observe in detail the dynamic of all individual activities of students learning electricity. Therefore all the activities of two groups of students learning this topic were videotaped, transcribed and analyzed.

Classroom setting and data collection

Our lessons were planned such that the students were able to interact with each other. During all lessons, students sat around tables in groups they had chosen themselves. The groups did not change during our investigations. So there were 3 groups of boys (with 2, 3 and 4 members) and 3 groups of 4 girls with members. The students were allowed to walk about the classroom to fetch experimental materials or interact with other groups or students. For data gathering we situated two video cameras in two corners of a normal classroom of the school high above students' heads. In each case, the camera focused on one whole of students.

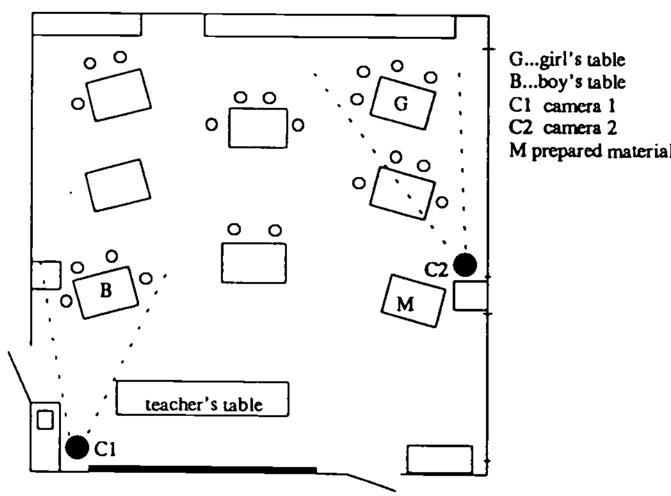


Figure 2: Classroom layout used in this investigation

The physics content

During 15 weeks, the students learned about many topics in electricity including contact electricity, test for charge, transmission of charges, influences, density of charges, polarization, energy of charge, capacity, voltage and electrical circuits (Ohm's law).

In all parts of the course, we organized opportunities for engaging in experimental activities. Different materials were provided for the investigations including plastic films, metal plates, pieces of cloth or dusters, little neon glow lamps, electrometers, rods and so on.

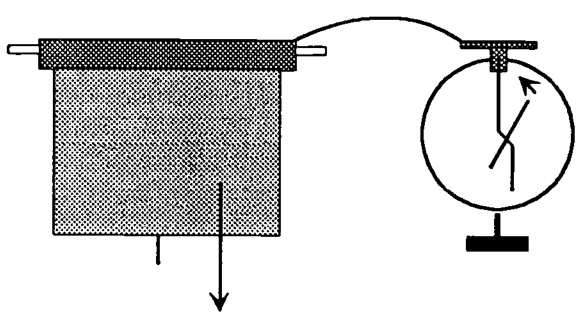
DATA INTERPRETATION

At first we watch the videotapes and write lists containing the sequence of events that made up the lesson. So we get a good overview about the (inter)actions during the lessons and can select areas for further analyses. We then select one group for analyze. The criteria for selection of any group for further investigation were completeness and the activity of the group members. The next step is to choose sequences of all activities to analyze according to the research questions.

The videosequences were transcribed, meaning, all observable activities (spoken words and sentences, gestures, mimic, the addressees in the communication...) are listed in chronological order and for each student. That is the first step of interpretation and requires some experience with such classroom contexts and with usual idioms of the participating persons.

The main step of the data interpretation is the reconstruction of students' "ideas". That is, every action of a student described in the transcript and observable on the videotape is interpreted as a spiral process of successive perception-expectation-action sequences. During these sequences situated cognition is constructed. The analyst formulates this in the form of "ideas". The analyst implies that this situation-related "idea" might be a cognitive construction that generates the action of the student. Result of this interpretational process is a chronological list of "ideas" for each student through all chosen sequences. The criterion for a correct interpretation of students' activities within the contexts observed is the consistency of the following activities (see also Lijnse 1995, 193). Our method is exemplified in the following:

10th grade - Electrostatics: Jessica and her group stand around the table and inspect a charged electroscope which is connected with a roller blind made of aluminium foil (see Figure 3).



roller blind electrometer

Figure 3: A roller-blind conductively connected with an electrscope will be enrolled

They want to find physical information about the density of charge on this apparatus. Jessica expects, that there is a change at the electroscope if she unrolls the roller blind. But when she does unroll the blind, she doesn't recognize an effect.

We have analyzed Jessica's actions and reconstructed her ideas within this short sequence on the basis of the spoken words and the actions. The following ideas (Jessica 1-3) describe Jessica's "situated cognition" (for further explanation see below):

Jessica 1: *The electroscope can't react to the motion of the roller blind because there is no more contact if the roller blind is turning.*

Jessica 2: *This can't be the fact, because one can charge the roller blind using the plastic film.*

Jessica 3: *The apparatus must be O.K.. All parts are conductively connected.*

Following these ideas you can see, that Jessica generates physics' ideas when she looks for mistakes in her actions and expectations. She assumes that the electrical contacts of the apparatus are faulty. So she improves her hypothesis and gives it up.

This short piece of reconstructed succession of ideas characterizes Jessica's process of "situated cognition - development". Again and again single individual situated cognitions are produced contextually (see idea 1, 2 and 3 above) and further developed. One idea comes after another, which is produced in a process of fitting perception-expectation and action. On the occasion every succession of ideas (e.g. succession of situated cognition) is related to the current context of activity.

RESULTS

We summarize the results of 7 completed and 3 nearly-completed case studies in the form of 3 assertions.

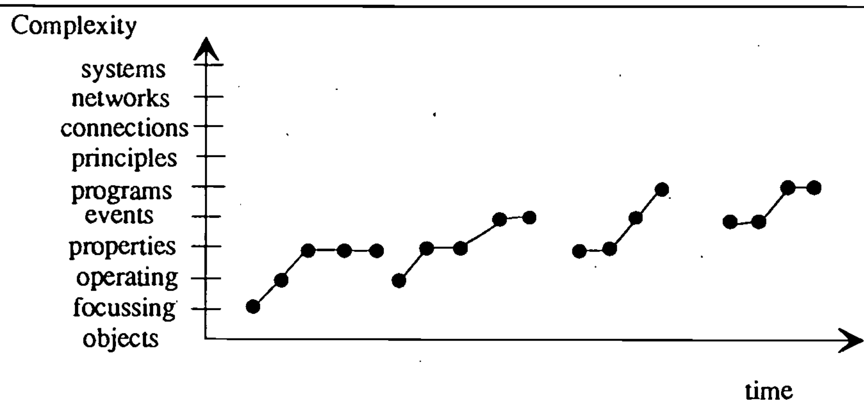
Assertion 1:

In each situation every student passes anew through a "situated-cognition-development." This "situated-cognition-development" (always) is characterized by an increase of complexity (bottom up).

Within each situation we can identify students' behavior: they talk, perform experiments, watch phenomena, write, and so on. This results in continuous changing learning environments - that means in ever new contexts of learning. When we follow the behavior of the students in such contexts we are able to reconstruct the situated cognition as "ideas". When doing this we begin to realize that students continuously construct physics meanings (or meanings related to the physics' context). On that occasion similar situated constructions (that also means similar ideas) are rather rare.

The development of situated cognition always passes through successive stages. These stages are the elements that are further developed in subsequent actions. This further development is realized by a circular process of fitting perception-expectation and action. On the occasion every succession of ideas (e.g. succession of situated cognition) is related to the actual context of the activity.

Differences in the complexity of ideas provide a quantitative criterion between ideas of several students in several situations. We found in each situation students begin new successions of ideas. These successions of ideas always begin (see Figure 3) at a low level of complexity and often reach higher levels than before (progression of complexity from first to fourth sequence in Figure 4). This developmental progression is independent of student and context.



development of situated cognition in a special context
each point is standing for one reconstructed idea

Figure 4 Increasing complexity of successions of ideas

Situated cognition therefore becomes increasingly complex during laboratory activities as a course progresses. We think about it as a "bottom-up-development" of complexity.

Assertion 2:

"Learning" as a process of drifting of successions of "situated-cognition-development" to higher complexity

We found that there exists a second kind of change in the dynamic of situated cognition when it is observed over several lessons of the physics course. (An idealized development is shown in Figure 5.)

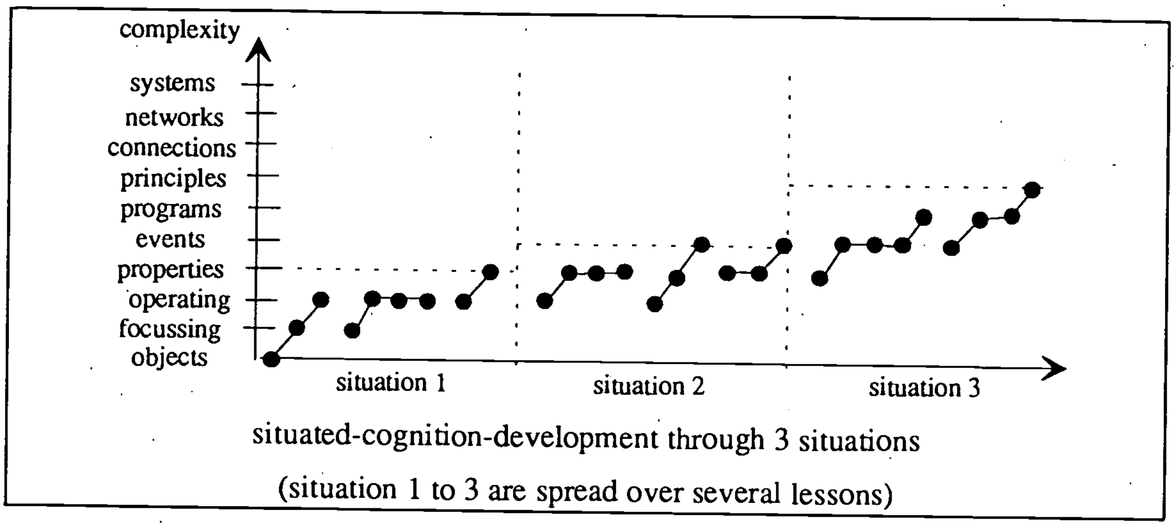


Figure 5 Changing of the dynamics of situated cognition

The level of complexity on which the successions of situated-cognition-development begin and end is drifting to higher complexity across successions of lessons. In the first period a low level will be differentiated (many ideas are successive on this level), after that a new and higher level with a higher complexity will be reached and then also differentiated. It is interesting, that the level the students reached before are reached more and more quickly if they have passed more (nearly similar) situations. That means, that an advanced student begins his/her situated cognition on a low level of complexity, and very quickly reaches the higher level (the same level reached more slowly in earlier situations) and makes a development of situated cognition on these higher levels. Doing this, the student differentiates the level reached and also attains higher complexity. A not so advanced student (a beginner in this context) also begins a situated-cognition-development on a low level of complexity, but needs more time to differentiate the low levels and to reach a higher level than that reached previously. So it is necessary to realize more similar situations for reaching the same level as the advanced student. But at the end of a course both have passed nearly the same development of situated-cognition-development. This pattern of individual development was observed in several case studies covering 8 students of different age groups and in different topics of electricity.

Assertion 3:

Situated cognition development in different age groups is different

When we compared situated-cognition-development in different age groups (but learning the same matter - namely electricity) we made some interesting observations:

- In grade 5 (age 10) there are mainly individual developments through the levels "**objects - focusing - operating - properties - events**". The level of "program" is reached very rarely.
- In grade 10 (age 15/16) mainly there are developments through the levels of "**properties - events - programs**". The level of "principles" is reached only during advanced lessons of the course.
- In grade 11 (age 17/18) (the second period of the year) there are developments through the levels of "**events - programs - principles**." The levels of "connections" and "networks" are reached only in advanced lessons of the whole course.
- The complexity reached depends on the students' interpretation of the situation and his/her experiences in the actual context.

CONCLUSIONS

These investigations convinced us that we need to describe "learning" as individual processes of a development of situated cognition. These processes are generated internally on the basis of experiences of a learner and according to the opportunities he/she has within the learning environments. Our results show that in learning processes no exchange of information take place. It is unusual to believe, that you have to tell someone special things and he has taken this in his mind.

Our results suggest that everybody always constructs and develops processes of situated cognition on the basis of his/her own experiences. Such processes of reaching higher complexity are context dependent and take place during all learning situations.

These studies allow us to plan courses in new ways other than the traditional way of telling students abstract things like laws and to illustrate these laws with examples. Rather we suggest to give the students all the opportunities to have experiences in the new (physics) context on lower level of complexity. Students have to understand by themselves which are the relevant objects and properties to manage a special situation, they have to act with them and to get experiences to predict events, when they combine properties of objects. After that they are able to progress to understand principles in the physical world and to a systematic view on physics. We agree with Lijnse (1995), who wrote:

> "In our opinion, a more radical change is needed. If we want students to really understand and use what they are taught, we should engage with them a „bottom-up" learning process. In analogy to Freudenthal, we could say that we should not teach the concepts of science (as a product), not even in

above-mentioned constructivist way, but guide the students in the activity of "scientificalizing" their world." (Lijnse, 1995, 192)

Advanced learners (such as students of upper high school and like new results at second year students of university in physics show), too, have to pass through such a development of situated cognition in each new situation of their learning environments beginning from a very low level of complexity and within learning environments which are normally more complicated.

In our future work, we now plan new courses to test hypotheses that arose from our previous work. For example we want to find out, how to organize the interactions and the opportunities of students to act within their learning environment. We want to find out, how to guide the students through their learning processes.

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