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How to interact with students?

The role of teachers in a learning situation.

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Investigating individual learning processes in the field of learning physics through experiments, one focus of our research interest is the influence of interactions on situated cognition. The main questions we wanted to answer are: (1) How do interactions influence cognitive processes? and (2) How should teachers interact with students to initiate learning in the intended way? To answer these questions videotaped sequences of interactive experimental classroom situations were analysed in detail. The results show that specific factors – content and complexity – influence the cognitive processes of students through interaction with a teacher. With this paper we will present selected data from experimental teaching situations to describe the influence of interactions on situated cognition and to derive possibilities for teachers to interact successfully within a learning situation involving experiments.

Theoretical background

Which of us – teachers and researchers – responsible for the teaching of a science discipline and using experiments for teaching does not recognise this experience: The students were given an experimental device and an appropriate task to solve, but they are not able to work on this task. They ask what to do and why to do it. A teacher explanation follows, well formulated and presented in a friendly way, and well structured. The students say 'Yeah. It is clear now'. The students must have understood, the teacher hopes. Now the students have to experiment and to formulate the answer to the problem in their booklet. But, they do not give a correct and complete answer or explanation. In the following discussion the teacher has to conclude that some of the students did not understand in the intended way what they have been doing all the time. What was going wrong there? Why did the students not understand the teacher's explanations? These questions lead us to ask for rules of interaction between teachers and students.

'A person's knowing of a conceptual domain is a set of abilities to understand, reason, and participate in discourse... Any particular activities that a person engages in or learns to perform are embedded in a conceptual ecology that has been developed within a community of intellectual work.' (Greeno 1991, p. 176)

Taking the cited perspective, learning can be seen in general as cognitive development through an apprenticeship in the practices of a culture (Brown et al. 1989, Rogoff 1990, Roth 1995). Apprenticeship is characterised by the opportunities for learning that are structured by participation in authentic practices. In each community, including schools, there are experts and novices interacting in order to organise learning. Conceptualising learning and teaching as interactions in a community of knowers (novices and experts) and seeing learners as independent agents (Agre 1993, Welzel & Roth 1998), the teacher has to be seen as a partner for interaction and for structuring learning resources such as environments, materials, discussions and hints to allow students to develop individual knowledge, to negotiate and to share it.

Usually, in contrary to this assumption, at school the job of a teacher is understood as acting as a medium for transmission of knowledge. However, many empirical studies show evidence indicating that the metaphor of teachers as a medium for the transmission of knowledge is wrong (Pfundt & Duit et al. 1991). Knowledge is not transmissible. Moreover, the teacher can only initiate specific activities of students during interactions (Welzel 1995) which allow students to construct and develop their own knowledge. But, the question is, how can this happen in a planned way – in the way intended by the teacher?

Using this theoretical background, we have been investigating the dynamic of situated cognition and learning of differently experienced students aged 10 to 25 years in the field of physics in experimental classroom situations in our research group for more than ten years (von Aufschnaiter & Welzel 1996; Welzel 1997). For these purposes we have developed a theoretical frame epistemologically similar to that of Clancey (1993). It may roughly be outlined with the demand: 'Try to understand cognition without using any approach of symbolic representation' (von Aufschnaiter & Welzel in press). As described in the paper of von Aufschnaiter, Schoster and von

Aufschnaiter (at the beginning of this section) 'situated' in this context means *situated in time*. From a neurobiological point of view the cognitive dynamic must be described as sequences of 'Images-of-now' (Damasio 1994). Each Image-of-now has to be 'produced' by the cognitive system (neuronal structure) within three seconds (Pöppel 1994). For experiences of a much larger time than three seconds, the cognitive system will produce sequences of Images-of-now which are connected to a greater or lesser extent, among other things, with changes in the learning environment.

Learning is correlated with 'the success' of sequences of Images-of-now when solving problems and leads to changes in the cognitive system (neuronal structure).

The aim of the investigations reported here was to analyse and describe in detail the individual processes of situated cognition and learning within physics learning environments on the short time scale of sequences of Images-of-now and the influence of several aspects of the environment on individual cognitive processes on that time scale.

Methodologically this results in a detailed analysis of individual actions and interactions in authentic learning environments – and this always means in social environments – comparable to the microgenetic method of Siegler and Crowley (1991). Following the activities of individual students during instruction and interaction in detail makes changes become visible: the number and type of elements the students use and relationships they construct (between these elements) during acting in a specific context increases (Welzel 1995; 1997). This development concerns their actions and their cognitions and can be described in terms of *increasing complexity of situated cognition* in a bottom-up-direction. We have been developing a heuristic that allows us to describe this kind of development by means of ten levels of complexity:

1 objects—construction of stable figure-ground-distinctions;
2 aspects—links between objects and/or identification of specific features;
3 operations—systematic variation of objects according to their aspects;
4 properties—construction of classes of objects on the basis of common and different aspects;
5 events—links between some stable properties of the same or of different class(es) of objects;

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6 programmes—systematic variation of a property according to other properties;
7 principles—construction of stable co-variations of pairs of properties; connections—links between several principles with the same or different variable properties;
9 networks—systematic variation of a principle according to other principles;
10 systems—construction of stable networks of variable principles.

Taking this heuristic to analyse reconstructed students' behaviour (subdivided on a time scale of three seconds; Images-of-now) it becomes possible to follow the dynamic of situated action along this behaviour and with this the development of situated cognition during interaction in a learning environment (Welzel 1997, Welzel & Roth 1998). Using it, we will see the moments of students' reaction on a teacher's hint or question and we can qualify the complexity of the students' reaction.

Thus, *interaction*, the *dynamic of cognitive development* and *complexity* are the theoretical and methodological bases for our investigations.

Research questions

On the basis of the theoretical background described above, we analysed the influence of teachers' interactions on students' individual cognitive processes in detail to find rules of interaction in a teaching-learning-situation. On the basis of these rules possibilities to improve communication and interaction in teaching situations will be derived and discussed.

The two main questions for this paper are:

(1) *How do interactions influence cognitive processes with regard to the time scale, its content, and complexity?*; and
(2) *How to interact with students to initiate learning up to higher complexity levels in the intended way, in certain subject areas?*

Methods

In order to answer the research questions videotaped sequences of students and teachers acting in physics lessons were analysed in great detail (for the procedure see Welzel 1995, 1997; Welzel & von Aufschnaiter 1997). Video-

data of a physics unit (15 double lessons) on electrostatics involving German High School students (aged 15), and university students (aged 21 to 23) acting in labwork sessions with a tutor and of sequences of private lessons on mechanics (age of students was around 17), were analysed. For this purpose, video-sequences with interactive situations were transcribed, and the students' cognitions and teachers' hints and questions were analysed according to their influence on students' situated cognition, the content of communication and the complexity levels reached.

Results

Analysing all the data we found that interactions influence individual cognitions on a short time scale of around 5 seconds (1). The results also show specific factors – content (2) and complexity (3) – influencing the thinking pathways of students through interaction with a teacher.

These results will now be examplified using data from the physics unit on electrostatics (taught in a grade 10 course of a German High School) and one example found in the literature. The literature example is used deliberately to demonstrate that the findings reported here are not artefacts produced with our own databases. The examples used in the paper are used only to *illustrate* the results found in a large number of interactive sequences detected and analysed in each of the data sets.

We will start with a general rule – the time scale of interactional influences. This will be followed by the content and complexity results.

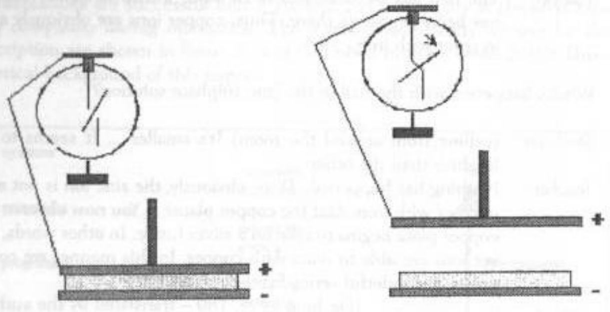
1. Interactions influence cognitive processes on a short-time-scale

Analysing our data we found out that interactions always influence cognitive processes on a short time scale of around 5 seconds.

See the following example

Situation: during the unit on electrostatics – four girls – Caren, Jessica, Inga and Birgit are doing an experiment. (See figure 1). The duration of the whole sequence is 25 seconds.

Between two charged metal plates a thin isolator is placed. One of the plates is connected with an electroscope. The upper plate ten will be moved upward.



If the above plate is moved upward, the pointer at the electroscope moves forward.

Figure 1: *Experiment with metal plates and an electroscope*

The teacher approaches and asks the students:

Transcript (translated into English; T – teacher, C – Caren, J – Jessica, I – Inga, B – Birgit)

01 T: What happens, when enlarging the distance between the plates?
02 C: The pointer on the electroscope moves forward.
03 B: (MOVES THE UPPER PLATE) Yes, then the pointer moves
04 forward.
05 I: It enlarges, the pointer ...
06 T: Now you have to write the observation down, and do you know
07 why this happens?
08 I: Do you have the answering sheets? Or, ...
09 T: (POINTS AT A SHEET ON THE TABLE) Yes, write it down on this one here.
10 I: O.K. Fine.
11 THE STUDENTS DO NOT WRITE.
12 T: Do you have an explanation for that?
13 I: That, because this is farther away now (MOVES HER
14 HAND AS THE UPPER PLATE), the electrons somehow
15 have to ...
16 B: The electrons here don't push off themselves anymore
17 (POINTS TO THE UPPER PLATE)
18 J: Yes, exactly.
19 B: They are moving over there (POINTS TO THE
20 ELECTROSCOPE) and push off themselves.

What can be seen in this transcript?

In the first part (lines 02 to 05) the students answer directly to the question asked by the teacher. The teacher is satisfied by these answers and asks the students to write down the observations and to think about an explanation (lines 06-07). At this moment the student Inga asks for answering sheets. She focused on the first part of the teacher's question. The teacher answers this question, but in line 11 it can be seen that Inga does not react to this problem any more. She does not start to write anything. Because of no further action the teacher again asks for an explanation (line 12) to the pointer's movement. Immediately again Inga reacts: 'That, because this is farther away ...'.

A few seconds later (outside this piece of transcript) the students discuss the attraction of the electrons to the positively charged plate in relationship to the forces between the electrons on the surface of the upper plate. While Jessica is giving a complete and correct explanation relatively quick, the other three students need more time for a step-by-step-explanation. They do not use the explanation formulated by Jessica, although they attended the group all the time.

What about the time scale on which interactions influence cognitive processes? In our example (line 06 to 08) Inga did only react to the first part of the teachers intervention (where to write the observation down). The teacher had to formulate the second part of the intervention (explanation) again after the negotiation of the first part (line 12).

How do interactions influence the cognitive processes? Looking at the second part of the sequence the analyst can see that all explanations of the other students, especially the explanation formulated by Jessica did not produce a prompt right answer (explanation) of the other students of the group. Thus, each of the students needs his or her own way of constructing knowledge. And, the students need time to do so.

How to interact with students?

To answer this question we analysed all the data mentioned at the beginning. On the basis of many sequences and results, such as the example described above, we have to formulate (preliminary) general rules with regard to the *time scale* and the *dynamic* of the influence interactions can have:

- Ask only single questions, do not use complex sentences, *the students can only react to one aspect.*
- *Initiate only* further thinking, do not tell a long story, the students start to think about your comments (explanations) at the moment they can link parts to own experiences

Thus:

- Do not expect the students to remember all you or others said before, they *can remember what they 'experienced' by themselves only* or what they are able to use at the moment.

2. Content dependence

Our data show that interactions are successful only if the contents the students and the teacher 'talk about' (construct) are the same.

This statement seems to be trivial, but mostly, interactions of teachers during practical activities concern 'new aspects' of the experiment which the students cannot follow.

The following example taken from a chemistry lesson may illustrate this phenomenon (We took this example because it is from a different science discipline):

EXAMPLE:

The *'reduction strength'* of different metals is to be compared. The teacher puts an iron nail for a few seconds into a solution of copper (II) sulphate. He repeats the experiment using zinc (II) sulphate. Finally he puts a copper plate into a solution of silver nitrate.

Teacher: Let's observe whether we can see anything. What do you see?
Student: The nail is coated.
Teacher: The nail has become brown. In other words: obviously copper has been deposited there. Thus, copper ions are obviously able to react with iron.

What's happened with the nail in the zinc sulphate solution?

Students: (calling from around the room) It's smaller ... It seems to be brighter than the other ...
Teacher: Nothing has happened. Thus, obviously, the zinc ion is not able to react with iron. And the copper plate? ... You now observe the copper plate begins to take on a silver lustre. In other words, silver ions are able to react with copper. In this manner we could create a wonderful series for the metals.

(De Jong 1994, 180 – translated by the author)

Following this interaction between teacher and students one can see that both teacher and students communicate different things: The students describe more or less their observations with regard to the nails. In contrast, the teacher quickly communicates the chemical reactions. An observer cannot see whether or not the students really understand these explanations. With this it is not quite clear whether or not the students could follow the teachers' explanations and whether or not they are able to construct appropriate cognitions.

How to interact with students?

We found a lot of situations like the one described above in our own data sets where interacting partners have misunderstandings. Often the interacting partners do not recognise that a misunderstanding is taking place. To avoid interactions like this we propose that teachers follow these rules:

- *Start* your interaction *with the content where the students are* to change the direction together with them.
- If the students do not give the expected answer, *check if there are misunderstandings* based on different thinking contents.

3. Complexity

Interactions are successful only if student and teacher are at the *same level of complexity during interaction*. The levels of complexity we use for description are shown in figure 2 (and described in more detail in the Theoretical background of this paper):

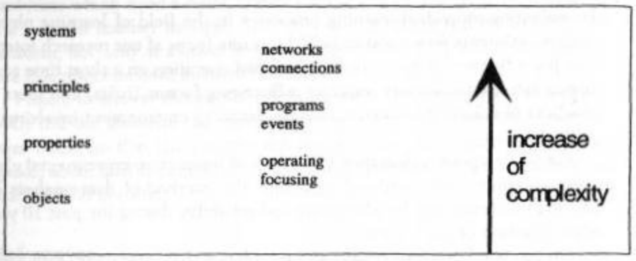


Figure 2: *Levels of Complexity*

Example for a successful Interaction

Let us go back to the first interactions of the example described above. In addition, now each statement has been analysed according to its complexity. The assigned level of complexity is noticed.

Example:

The teacher approaches and asks the students, who are experimenting with the metal plates and the electroscope:

T: What happens, when *enlarging the distance* between the plates?
(She is varying the property of 'distance' – program)
C: The *deflection* of the pointer at the electroscope *enlarges*.
(She is varying the property of 'pointer's deflection' – (program)
B: (MOVES THE UPPER PLATE) Yes, then the pointer moves forward.
(She is linking the lift of the plate to the pointer movement – event)

I: It enlarges, the pointer ...
(She is varying the objects 'plate and pointer' – operation)
T: Now you have to write the observation down, and do you know why ...
(She is reacting to C's answer mainly)

The teacher at the beginning is formulating her question on a program level (constructing distance as a variable property). As the students were experimenting before and as they did vary the distance of the metal plate this level is appropriate to be used at this moment. It can be seen, that Caren (C) answers this question immediately at the same level (program). She talks about the change (variation) of the deflection. Both of them have been at the same complexity level.

But, looking at the answers of Birgit (B) and Inga (I) it seems to be that both of them did not reach the program level yet. They are at lower complexity levels, and the teacher does not notice it. She supposed that she had got the right answer from all of the three students. Thus, it seems to be obvious that the teacher goes further and asks for an explanation (see the full piece of transcript above).

This short sequence shows a partly successful interaction between teacher and the students.

Unsuccessful interactions

We have found a lot of similar situations with regard to unsuccessful interactions because of the mismatch of the complexity levels.

For example: In a teaching situation during the second lesson, after experimenting with different materials the teacher intends to repeat together with the students the experiences the students made during experimenting with different material. The students in the last lesson first made experiences at lower levels of complexity – up to the property level. The teacher starts to ask a 'triple-question' (see the transcript below) at a complexity level the students did not reach before – at the program level. Thus, the students are not able to understand what the teacher wants them to answer. The teacher tries to ask again, but at the same level. Until she asks at the property level, the students are unable to answer:

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Transcript:

T: I ask you what happens while rubbing objects or, *how do these states of charge emerge*? Did someone of you hear about that before?
(The teacher asks about variation of the property of charge – program)

No reaction

T: What happens *while charging*?
(The teacher asks for linking the property of charge to other properties – event)

No reaction

T: Try *an explanation*.
(This is the same as before – event)

No reaction

T: What happens *while rubbing*?
(The teacher asks for linking concrete actions – operation)

Reaction *(operation and property)*

How to interact with students?

Students pass a cognitive development when managing a situation. Within a series of other empirical studies we found out that this development is bottom-up in complexity and always starts at a low level (see Schoster & von Aufschnaiter in this section, and Lang 1998, Schoster 1998, Welzel 1995, 1997, Welzel & Roth 1997). Taking our example and, in addition, the results of the data analyses we mentioned, we summarise as follows:

- If you want to know what the students already know about a subject, *remember first what they did last time*, and *start to ask at a low level of complexity* (objects, properties...), guide them through the situation.
- If you want to give a hint during students' activities, *first observe* their activities and see *at what level they are*:
  - do they handle certain objects?
  - do they handle properties?
  - do they vary properties?

  Then formulate your hint *at the same level* (name or handle objects, name properties or focus on variation of properties).
- If you want to *guide students* to bring them towards a 'right way', look where they are, start there and then go further (in content and complexity). *The students cannot understand principles or laws at the beginning of a learning process.*
- If tasks or problems need a too high level of complexity for solution, the students are not able to solve them. *Learners always interpret tasks on a complexity level they already reached before.*

Conclusions

Investigating individual learning processes in the field of learning physics with experiments on a constructivist basis one focus of our research interest was the influence of interactions in situated cognition on a short time scale. It was intended to extract concrete influencing factors (rules) and hints for teachers to behave appropriate within a learning environment involving experiments.

For this purpose, videotaped sequences of interactive experimental classroom situations were analysed in detail. The method of data analysis described was tested out for objectivity and reliability during the past 10 years with members of our institute.

On the one hand, our results show evidence that interaction exclusively on a short-time-scale influences situated cognition development of students. For interacting with students in a learning environment involving experiments, this leads to the recommendation to teachers only to ask single questions, and not to use complex sentences, because the students can react only to one aspect. Knowing this, a teacher exclusively can initiate a further thinking, therefore it is not useful to tell 'long and new stories', as the students always start to think about details of explanations at the moment they can link it to own experiences.

On the other hand we can identify the content of communication and the complexity of situated cognitions and actions as specific factors influencing the thinking pathways of students through interaction with a teacher. Out of this we conclude that interactions are successful only if the contents the students and the teacher 'talk about' (construct) are the same. Interactions are successful only if students and teacher are at the same level of complexity during interaction. Taking this into account a teacher who is trying to assess what the students already know about a subject, has to remember first what the students did last time, and has to start to ask questions at a low level of complexity for guiding them through the situation. If a teacher wants to give a hint during students' activities, he or she has first to observe the students' activities and to see at what complexity level they are. Then he or she can formulate hints at the same level. For guiding students towards a 'right way' through an experimental situation, the teacher should look where the students are in terms of content and complexity, then start there and go further. The students cannot understand principles or laws at the beginning of the learning process. As learners always interpret tasks on a complexity level they previously reached, the students are not able to solve tasks or problems which need a much higher level of complexity for their solution in the way the teacher intends. Moreover, the students will try to solve this problem, but 'only' at a lower level of complexity. If the teacher does not notice this phenomenon, misunderstandings can occur.

Finally, to answer the question formulated at the beginning of this paper: 'Why did the students not understand the teacher's explanation?', one answer could be that the content the teacher and the students thought (or spoke) about and/or complexity of the communication between teacher and students did not match.

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