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Misconceptions or Missing Conceptions?

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Research on conceptual change assumes that students enter a science classroom with prior (mis-)conceptions. When being exposed to instruction, students are supposed to develop or change their conceptions to (more) scientific concepts. As a consequence, instruction typically concentrates on appropriate examples demonstrating that students' conceptions are limited and need to be extended or revised (*Posner criteria*). Based on our studies on students' conceptual development in Physics, we rather argue that students typically lack any (explanatory) conceptual understanding of the science content offered. We therefore conclude that a focus on missing conceptions is much more promising than a focus on misconceptions. This paper addresses theoretical arguments and empirical results supporting our proposition as well as suggests possible implications for the design of instruction and for teacher education.

Keywords: Conceptual Change, Conceptual Development, Learning Processes, Video, Physics.

INTRODUCTION

Conceptual change research has been a major focus of science education research throughout the last 30 years (e.g., Duit, 2009). Some of the instruments developed within this research are very popular and frequently used for study purposes, such as the "Force Concept Inventory" (Halloun, Hake, & Mosca, 1995). One of the items included in this questionnaire is presented in Figure 1. The item addresses a common misconception of (physics) students who assume that moving an object at any speed requires a (resulting) force, even if speed and velocity do not change.

Within the university curriculum for prospective teachers we sometimes ask our students to complete the "Force Concept Inventory" together with a partner. Their discussions about the items are documented on video in order to find out how the students conceptualize the context given and what their arguments in favor or against a specific answer are. With one student group (21 years old) the following discourse about Item 25 (Figure 1) occurred:

S2: […] Well, I would say greater, isn't it?
S1: Greater? (reads aloud) "than the total force which resists the motion of the box." (reads) "greater than the weight of the box." I don't understand…
S2: (interrupts) But no, wait. Hold it. Same magnitude, because the box is moving already. We don't have to accelerate it. It says "the box moves at a constant speed", that is, it moves. (indicates movement on the table) And we are right in the middle of the movement. Therefore, they have to have the same magnitude.
S1: Well, you mean, it's the same as the example with the lorry, only different?
S2: I don't know, I don't think so. But if they had the same magnitude, then they would stand still, wouldn't they? (indicates stopping with his hands)
S1: Oh gosh, what a mess!

Transcript 1. Two university students discuss Item 25 from the Force Concept Inventory (duration of the excerpt: 35 seconds).

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State of the literature

- Current research offers a large number of references about students' misconceptions in various science topics.
- Current research offers assumptions, ideas, and approaches on how to help students to overcome their misconceptions in various science topics but has rarely investigated in detail how students work on the instruction offered, rather.
- Typically, research concentrates on a particular topic and describes learning difficulties and approaches towards overcoming these difficulties within this particular topic. Thus, a transfer of results to other topics is often not straight forward.

Contribution of this paper to the literature

- The paper offers ways to investigate and analyze students' learning processes with video in order to infer how students arrive at any conceptual understanding and which instruction does have a positive impact and when during learning.
- The paper offers new insights into how students develop conceptual understanding (either correct or incorrect). It describes conceptual development as a process that develops from explorations to intuitive rule-based and then to explicit rule-based understanding.
- Categories used to describe conceptual development can possibly be transferred to any science discipline and can be used to design instruction of appropriate learning demand.

A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "v_0".
The constant horizontal force applied by the woman:
(A) has the same magnitude as the weight of the box.
(B) is greater than the weight of the box.
(C) has the same magnitude as the total force which resists the motion of the box.
(D) is greater than the total force which resists the motion of the box.
(E) is greater than either the weight of the box or the total force which resists its motion.

Figure 1. Item 25 from the Force Concept Inventory (Halloun, Hake, & Mosca, 1995).

The interesting bit about this transcript is that student S2 changes his understanding of the situation twice. Initially, he argues for answer D (which is wrong) but then seems to realize that it is answer C because the box moves at constant speed and is not accelerated. He also demonstrates the process with his hands. Finally, he switches back to answer D by asking himself (and his peer) that the box would come to rest if forces have the same magnitude. Interestingly, S1 compares this task with another one from the questionnaire in which a car pushes a lorry. S1's remarks show that even though S1 seems not to know the appropriate answer he has some understanding of which examples are similar.

The excerpt clearly demonstrates that looking only at the answer students choose in the questionnaire does not say very much about their understanding. Also, it does not reveal which cross-references they make in order to solve this task and how they incorporate (conceptual) understanding into their considerations. If the students from Transcript 1 opt for answer C it would be assumed that they possess the correct concept (at least within this context). Would they opt for D it is suggested that they have a misconception. Conceptual change research traditionally regards conceptions as something a student possesses. As a consequence, research investigates the conceptions students have prior and/or post to instruction. This kind of research has revealed students' typical misconceptions and can also generate global results on which instruction is more effective than other. Describing precisely how students utilize conceptual understanding while working on particular experiments, problems, and tasks would require more in depth-studies which are sometimes conducted through interviews (e.g., Ioannides & Vosniadou, 2002; Sherin, 2006; Slotta, Chi, & Joram, 1995). Similar to our example in Transcript 1 an interview can provide more information on how students conceptualize problems and in which way they generate a solution. However, students often tend not to discuss their problems as openly with an (expert) interviewer. In order to avoid this situation one rather confronts a team of two (or more) students with typical problems to work on. This way students discuss their ideas and misconceptions more open and vividly, especially when they are told that they have to agree on one answer.

Despite the important information one gains when assessing students' conceptions either with tests, questionnaires, or interviews it is mostly impossible to retrieve information on how these conceptions have developed over time. For example, in Transcript 1 we do not know how S2 has grasped the idea of Newton's first Law. Neither do we know what makes him assume that the pushing force needs to be greater than all other forces. In addition to describing what kind of conceptions students "possess" research focusing on how students *establish* and use conceptions would provide helpful insights about *mechanisms* of learning and teaching (see also Siegler & Crowley, 1991). These mechanisms can then be used to infer about teaching approaches.

In our research we therefore focus rather on learning processes instead of learning outcomes only. With this approach we can describe in detail how students develop conceptual understanding and how they use their understanding while working on physics tasks (e.g., v. Aufschnaiter & v. Aufschnaiter, 2003a). Empirical results are also used to establish theoretical descriptions about conceptual change processes. Results of this research are used to develop methods and criteria for the design of learning environments in physics that take students' processes of concept formation into account. Finally, content and structure of our teacher education are designed according to the results on processes of concept formation. Therefore, the main goal of our research is to explore, describe, and theorize the mechanisms of teaching and learning physics. In this paper we present a summary of our recent work, including a detailed description of our process based analyses of concept formation and concept use. Also, we provide information on how we design learning material with respect to our results. Moreover, we report our results and discuss their possible impact on teacher education.

Investigating processes of concept formation and concept use

Video as a means to investigate teaching and learning processes

Like many researchers we use video documentation to assess students' learning processes. Often, video-based research focuses on teacher activities in order to characterize the quality of instruction. If possible, two cameras are used, one of which focuses on the teacher (Figures 2a,b) and one of which is directed towards the whole class (Figures 2c,d). The teacher camera focuses on the teacher activity. It is a moving camera capturing experiments he/she is carrying out, his/her writing on the blackboard, his/her contribution to group work etc. Therefore, the teacher camera "captures the teacher-student-interactions completely and further interactions that characterize the teaching process as comprehensively as possible." (Seidel, Prenzel, & Kobarg, 2005, p. 32). The classroom camera is typically either a fixed camera or a moving camera (moving from student to student/from group to group).[1] The main

Figure 2a. Screenshot from a teacher camera (camera position does not exactly match Figure 2b).

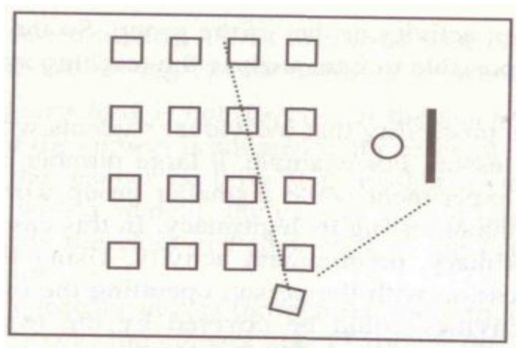

Figure 2b. Typical position of a teacher camera (Seidel, Prenzel & Kobarg, 2005, p. 33).

Figure 2c. Screenshot from a classroom camera.

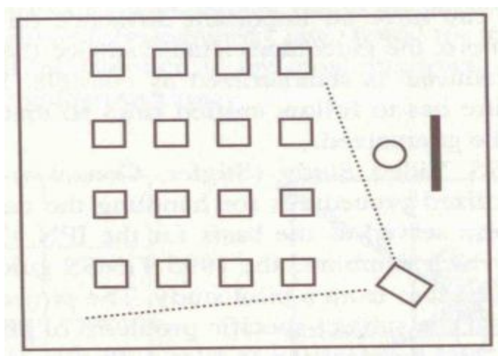

Figure 2d. Position of a classroom camera (Seidel, Prenzel & Kobarg, 2005, p. 32)

purpose of this camera is "to film as much as possible of what is happening in the entire classroom. Further, it should compensate any possible loss of information from the […teacher] camera." (Seidel, Prenzel, & Kobarg, 2005, p. 33).

Even though this procedure is very popular in video-based classroom research (e.g., Jacobs, Kawanaka, & Stigler 1999; Seidel, Prenzel, & Kobarg, 2005) it also has at least one limitation which is obvious from the quotes presented above: Neither a fixed nor a moving classroom camera can reveal how in detail students understand the instruction. Do students work on the instruction as expected? How long do they talk about the content, when are they off-task (and why)? How about individual differences? Also, almost no information can be gained on how in detail students develop conceptual understanding and use their knowledge while working on tasks and problems.

In order to gain more information on students' learning processes we use cameras and microphones which focus on student groups (typically two per classroom). Screenshots and position of camera for different instructions are presented in Figures 3a-d. We are well aware that a group focus is usually limited to a small number of groups and, thus, to a small number of students per class. Therefore, we also do not gain information on *all* students of *one* class. However, we asses about 20% of the students in great detail and receive our information about learning processes from the large number of students incorporated into different studies (see below). In addition to details of group work and individual processes we can usually also assess all teacher and student statements in teacher centered phases. Our cameras remain fixed without any camera person, but in classroom settings we usually have an observer sitting in the back of the room who takes notes on what is written on the blackboard and happening at the teacher's desk.

Obviously, investigating some or all students in a classroom in great detail causes more effort than focusing on the class as a whole. However, there is at least one more possible reason why video as a means to focus on learner activities is still rare in (large scale) video studies: The quality of instruction can be described and judged from an observer's point of view. An (expert) observer can assess whether the instruction is correct or incorrect, whether it is coherent or incoherent, whether the teacher dialogue is authoritative or dialogic, or whether the presented problem is demanding or simple (for according codes see for example Mortimer & Scott, 2003; Seidel, Prenzel, & Kobarg, 2005; Widodo, 2004). In contrast, if the interest lies on the students' performance it is important to understand how a particular student interprets the

Figure 3a. Teaching experiment with grade 11 students (electrostatics).

Figure 3b. University laboratory (RC-elements).

Figure 3c. Classroom instruction with grade 5 (electric circuits) (Buchmann, 2006).

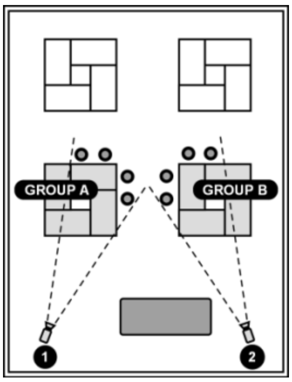

Figure 3d. Position of camera in the classroom on Figure 3c (drawing from K. Buchmann).

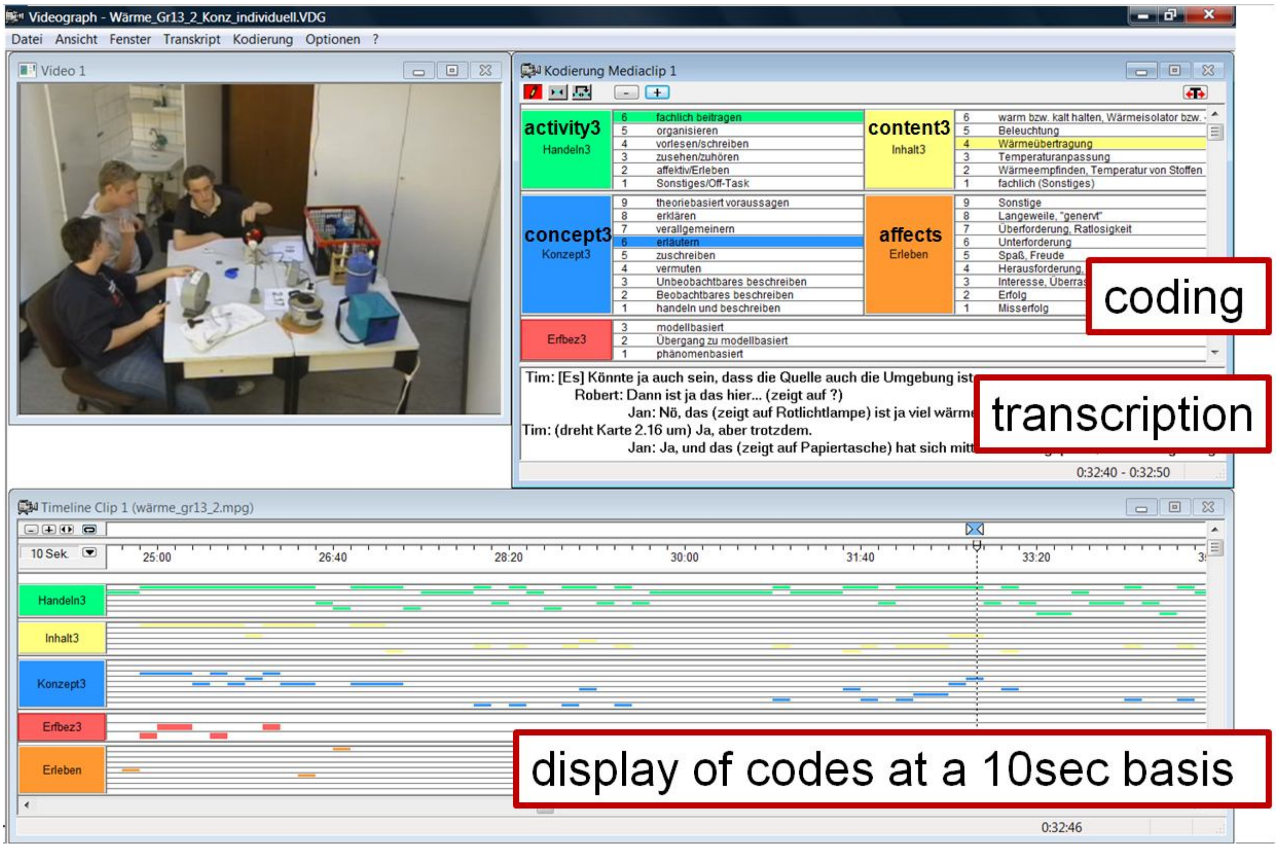

Figure 4. Screenshot from Videograph (codes and transcript in German).

instruction: Is the "simple" task really simple for that learner? (For all learners in the group?) Does the learner realize that a given information is correct or incorrect? Is the learner (surprisingly) content with the authoritative teacher? Is a repetition really repetitious for the learner (or does he/she experience the information as being new)? All these questions require seeing the world "through the learner's eyes". Marton and Booth would describe the former focus as a 1st order perspective, whereas the latter is referred to being a 2nd order perspective (e.g., Marton & Booth, 1997; Marton & Pang, 2008). The challenge of a 2nd order perspective is to avoid interpreting learner activities with the observer's understanding. For this reason we orient as close as possible on students' activities rather than assuming any conceptual qualities behind these activities (see also v. Aufschnaiter & v. Aufschnaiter, 2003a).

Samples and Methods

During the last 12 years we have investigated more than 150 students from lower and upper secondary (11 - 18 years old) (e.g., v. Aufschnaiter 2006a,b; v. Aufschnaiter & v. Aufschnaiter, 2003a) and from university level (typically about 21 years old) (e.g., v. Aufschnaiter & v. Aufschnaiter, 2007). Even though we have done some classroom studies, our main emphasis within the last years has been put on laboratory studies similar to teaching experiments. These investigations have the advantage that parameters can be controlled better than in classroom settings which helps to identify relevant processes. Currently, we turn our focus back to classroom settings in order to investigate whether processes are similar to those in our laboratory.

Topics of our investigations cover mainly electrodynamics but also thermodynamics and optics. Students are followed in small groups of two to four students with video typically over several successive lessons or sessions. In addition to video we sometimes assess students' interests and their situated experiences with questionnaires (e.g., v. Aufschnaiter, Schoster, & v. Aufschnaiter, 1999) and document their processes of concept-mapping.

Video-data are analyzed with a multilevel approach. In order to get an overview about the data and to generate quantitative results, videos are coded in 10 second intervals. These coding procedures focus on general dynamics and distinguish, for instance, between organizational and content-specific student activities or assess different types of discourse or student argumentation. Also, coding of video is used to identify sequences which are interesting for a specific research question. These sequences are then transcribed and investigated in more detail. Coding of the videos and transcription is performed with the software "Videograph" (Rimmele, 2008, see Figure 4).

The second step of our analyses are in-depth investigations of the transcript (together with the video data) in order to assess details of individual meaning making processes (e.g., how a student understands tasks or contributions from other students). The notion of "processes" refers to the time scales on which we assume cognitions to change. Humans typically change their clothes on a daily basis, so "processes" here would refer to 24 hour-intervals. Moods in contrast might change very quickly, so that intervals need to be much shorter (maybe on a minute-basis). Research on human cognition indicates that immediate behavior is "always new; always a sensorimotor circuit." (Clancey, 1993, pp. 111). From this and other work (e.g., Pöppel, 1994) we assume that a mental image (one cognition) takes up to 3 seconds and a line of thought takes up to 30 seconds (v. Aufschnaiter & v. Aufschnaiter, 2003b). Thus, "in-depth" analyses not only refer to close investigation but also to rather short time scales (utterance by utterance, activity by activity).

In our research, step 1 (coding of videos) and step 2 (in-depth analyses of transcripts) are interrelated. In both steps criteria are used to describe processes or criteria are generated. Thus, the approach is explorative but also tests hypotheses. Which codes are applied or developed depend on our specific research question. We want to stress that this criteria-based approach differentiates between "case stories" and "case studies". For case stories, individual learning (and teaching) processes are described in great detail such as what students do and how they do it. Even though these often result in vivid and interesting descriptions, the implications of these descriptions often remain unclear. However, they often cannot reveal commonalities and differences between different individuals. Here, clear criteria are needed as well as coding scheme (an example is given in Appendix 1) that help to set-up valid coding procedures (including the calculation of the intercoder reliability). With thorough coding procedures, individual processes can be compared and hypotheses can be formulated (see also Jacobs, Kawanaka, & Stigler, 1999).

Missing conceptions and (mis-)conceptions: Some empirical results and theoretical considerations

Conceptual qualities

In our earlier work on students' learning processes in physics we have noticed that students fairly often talk about particular situations, phenomena, or objects (e.g., v. Aufschnaiter, 2006b). This happens even if students are explicitly asked to generate a rule, such as with the example presented in Transcript 2. Before the question is presented to the students they already realized that the temperature of an object adapts to room temperature if the object remains in that particular room for some time. With the question offered in Transcript 2 we expected students to generate an answer such as "The object will get the same temperature as the warm environment." Rather than presenting an answer like this, the students discuss two different phenomena. First an experience with a snowball is reported and then the student S2 tries to create a specific situation when considering what happens to the temperature of a metal cube.

"Imagine a cold object is brought into a warm environment. Explain without measuring: What happens to the temperature of the object?"
S3: For instance, during summer a friend had a snowball which he took out of the freezer.
S1: If you take it from the cold to the warm environment it either melts or…
S2: Did it melt? How quickly?
S3: That was during summer. It melted within 20 seconds, maybe even quicker.
S2: Ok, if I take this metal cube in a real warm environment. Right now, this cube has about 22.5 degrees Celsius. It would then have about 25, I reckon.
S3: Not more than two degrees warmer, the most.

Transcript 2. Students discuss a question (unit on heat transfer, sequence shortened, duration about 1:30 minutes).

Similar to this example students often report descriptions of particular events or ask for them. They describe their observations or remembered phenomena, for instance: "Look, the metal cube feels cold but it has 22°C.", "Does this lamp still shine so brightly if you add a second one in this circuit?", or "Last time in the cinema, I could see how the light traveled to the screen." On the other hand, students sometimes explicitly state a rule, for instance: "Even if two objects feel differently warm, they can have the same temperature.", "If you add a lamp in a series circuit, all lamps will shine less brightly.", or "Light always travels in strait lines." This distinction between concrete events and rules which we found in our data concurs with arguments claiming that conceptual knowledge refers to an "implicit or explicit understanding of the principles that govern a domain […]." (Rittle-Johnson, Siegler, & Alibali, 2001, p. 341; see also diSessa & Sherin, 1998).

In our data, students only explicitly express conceptual knowledge in less than 20% of the time spent with the instruction. That is, dealing with specific objects or phenomena makes up the majority of students' activities. However, we identified in these activities another distinction which is also present in Rittle-Johnson's quote from above: "implicit […] understanding of the principles that govern a domain […]." (Rittle-Johnson, Siegler, & Alibali, 2001, p. 341). When following Transcript 1 it seems that the student

S2 has grasped conceptual ideas (both correct and incorrect) when he tries to decide whether the forces compensate or not. But he does not explicitly say something like "If an object is moved (moves) at constant speed (and velocity) all forces acting on the object compensate to zero." (Or "Whenever you want to move an object at steady speed you need to exert a (constant) force on the object.") In addition to distinguishing between activity which does not explicitly refer to conceptual understanding and statements in which conceptual knowledge is explicitly expressed we, therefore, identify an intermediate level. At this level, students predict specific events or phenomena, they attribute expressions (for instance, physics terms) to events, phenomena and objects or they describe how different aspects relate to each other. However, even though at this level students seem to have an intuitive understanding of the underpinning concepts, their explicit verbalizations refer to particular events. When students use physics expressions these serve as labels rather than as generalizations (concepts). Examples for this intermediate level of conceptual understanding are: "I reckon, you'll measure again something like 22°C", "This is the same electric circuit than we had yesterday.", "The shadow is there, because the light cannot pass this box.", or "Last week, our teacher told us to say 'energy' when talking about this situation."

The more experienced students will more likely action the basis of an intuitive understanding. In a comparison between students from grade 8 (about 13 years old) and grade 11 (about 16 years old) who were working on an identical unit on heat transfer (see Transcript 2 for a group of 8 graders and Table 1 for examples of the material) the 11th graders developed significantly more ideas which are based on an intuitive understanding (Rogge, 2009; Rogge, in preparation). We have not yet identified significantly more explicit conceptions with the older students. This result seems to be disappointing because differences between novices in physics and students who have had physics for at least 4 years in school appear to be rather small. However, it has to be noticed that distinguishing between concrete, intuitive, and explicit conceptual understanding is only one way to characterize the quality of students' understanding. In addition, descriptions can focus on scientific appropriateness, complexity of ideas, or time needed to construct these ideas (e.g., v. Aufschnaiter & v. Aufschnaiter, 2003a). Differences between less and more experienced students' knowledge of physics might, therefore, not include more explicit conceptions and/or these being scientifically (much) more appropriate. Rather, differences might refer, for instance, to the amount of different elements of the content integrated and/or the speed with which these are developed (see also v. Aufschnaiter, 2006b; v. Aufschnaiter & v. Aufschnaiter, 2003a).

From conceptual qualities to the learning of concepts

In the previous section, three different conceptual qualities were established from the discussion of examples (for a more detailed description of these main categories and related subcategories refer to Appendix 1):

1) Students argue and behave in a way that seems to have no conceptual ground, for instance, while "simply" describing what they observe or exploring what happens when they change something in an experimental set-up. In our research we would label this an **explorative approach.**
2) Students argue and behave in a way which indicates that they have already grasped some idea about underpinning rules but do not yet explicitly refer to these rules. For instance, they predict purposefully (but not based on explicit generalizations) what will happen next or they have grasped how to describe a particular event with physics expressions. These activities are labeled as **intuitive rule-based approach.**[2]
3) On the third level students explicitly express conceptual knowledge by generalizing over several events, objects, or phenomena. This is what we label as **explicit rule-based approach.**

Whereas levels 1 and 2 imply that students deal with particular events, level 3 refers to a conceptual level. The notion of "missing conceptions", therefore, refers to levels 1 and 2. At these levels, students either lack any conceptual understanding of that particular topic or are currently not explicitly expressing their understanding.

Distinguishing different conceptual qualities is useful to identify at which level students currently behave (see also coding scheme in Appendix 1). However, it does not provide any hints on how students move between levels, whether there is a definite level at which they start their movement, and which learning material promotes or hinders such movement. Our results on students' learning processes indicate that for any new aspect of a topic (new for the students) students start by exploring related phenomena, opportunities to solve tasks, to treat experiments and to verbalize aspects (level 1). If instruction offers explicit concepts at this level students either seem to "ignore" the information, express that they are puzzled or develop a concrete understanding of the information (for instance, by creating an example that matches from their point of view). At this level 1, students' activities often seem to follow a trail-and-error-like behavior, especially for open instructions. Teachers then often realize that students seem not to follow the instruction and do not control parameters.

Table 1. Examples of the instruction from a unit on heat transfer (Rogge & Linxweiler, 2008) aiming to establish conceptual understanding about the adaption of temperature (thermal equilibrium)

Tasks for students (partly shortened, pictures and lines for notes excluded)
1 Take a pair of scissors out of the box. How warm do the scissors seem to be? Do all parts of the scissors seem to be equally warm? Tip: Hold the scissors at the back of your hand or at your cheek.
2 Analyze different objects in the material box with respect to how warm they feel. Assign the objects to a) feel warm, b) feel normal, c) feel cold.
3 Roughly estimate temperatures of the objects in groups a), b), c) of card 2.
4 Measure the temperatures of the scissors' handle and blades. Measure all temperatures of the objects you have used for card 2. [All temperatures have to be noted on this card.]
5 What do you observe when comparing measured temperatures of the objects from card 4? […] Compare these temperatures with your estimations from card 2. What do you notice?
7 Use the surface thermometer to measure the air's temperature. Compare this temperature with the objects' temperatures from card 4. […] What do you observe?
8 [Thermometers placed in different objects in a closed electric cooler.] Consider which temperatures will be shown without looking into the cooler.
9 [Students have to look at all thermometers including one that is lying on the ground of the cooler.] What do you notice?
Information 2 *Objects sitting together for a long time have the same temperature.* If objects sit for a longer time in the same room with a specific air temperature, all objects have the temperature of the room. Which temperature would the objects in the material box have if the room would be at 30°C?
13 You've just observed that hot water cools down and that cool water gets warmer (card 11). Also, a cold plastic knife gets warmer (card 12). Consider: To which temperature will the hot water decrease? To which temperature will the cold water and the cold knife increase? You can use your observation from card 7.
14 Imagine, you would bake cookies in an oven at 200°C for half an hour. Afterwards, the cookies have to cool down for a while. Which temperatures will the cookies have right when they are coming out of the oven? Which temperatures would the cookies reach when sitting for a long time on the kitchen table?
15 Imagine, a cold object is brought into a warm environment. Explain without measuring: What happens to the temperature of the object?
Information 4 If objects or substances are in an environment (e.g., a room, a fridge, an oven) for a long time they will have the same temperature as the environment. If an object or substance is initially at a different temperature it will reach the temperature of the environment by getting warmer or getting cooler.
18 [A plastic knife has to be heated with a lamp.] Consider, which temperature does the knife have before being heated?
One week later
1 [Four gel-packs lying in hot water. Students have to measure the temperature of one of these gel-packs.] Explain without measurement why the other gel-packs should have the same temperature.
2 [Picture: A cup of hot tea which is sitting on a table.] How long will the temperature of the tea decrease?
6 [Similar to 1 with four cold gel-packs from the cooler.]
11 [Plates made from different material on which ice cubes have to be placed in order to observe their melting process.] Explain why all these plates roughly had the same temperature before putting the ice cubes on top of each of them.
14 […] Why does the small paper bag increase its temperature when being touched for a longer time with your hand?
25 Imagine, you are in a park on a sunny day with about 28°C. You have a bottle of lemonade with you which comes from the cooler and has about 10°C. What will happen to the temperature of the lemonade if you don't drink it?

Table 2. Examples of phenomenon- and model-based concepts

Phenomenon-based concepts	Model-based concepts
Whenever my teacher says "Ohm's Law" he wants to hear V=R • I.	Internal energy is the total amount of energy in an object.
If you add a lamp in a series circuit, all lamps will shine less brightly.	In order to see an object light has to be scattered from the object into our eyes.
Even if two objects feel differently warm, they can have the same temperature.	Sound is transferred by pressure variation.
All force meters include a spring.	Whenever an object changes its movement a force is exerted on the object.

From their explorations students develop an intuitive idea what will happen next or how they have to work on an experiment or a problem in order to get a specific result. From their explorations of ways to express things they also develop an intuitive understanding which words/phrases refer to which situations. Students who have some experiences on a particular aspect of the topic already sometimes almost directly start at an intuitive rule-based level when dealing with that aspect. Intuitive rules stabilize while students work on similar phenomena and problems. In these phases, students often explore the learning material again even though they already have an intuitive idea what will happen. Within this circular movement between levels and also within the same level students are also more and more able to integrate different content elements into their considerations.

Surprisingly, students rarely move to the next level 3. Explicit conceptualizations often occur in single sentences but not in long and extensive discussions. Moreover, students typically express a rule after they have already developed an intuitive understanding of this particular rule. However, conceptual understanding is usually expressed only after students' explorations of specific phenomena and problems. That is, students very rarely construct a hypothesis which is explicitly based on a conception before they work on the relating problem. While moving from level 2 to 3 and at level 3 explicit (short) information on underpinning concepts seems to be useful. Other than at an early stage of their learning, conceptual explanations offered help students to realize that they are "on the correct way" or have not fully grasped the idea. That is, if instruction wants students to understand a particular concept, these students need to discover this concept at least intuitively *before* they are likely to grasp the related conceptual information. Or, conversely, students are likely to understand any concept that they already "know" at least intuitively. However, it should be noted that establishing a concept once is not enough for a robust understanding. Even though we do see a general movement (for a specific aspect of a topic) from level 1 to level 3, a "robust" understanding at level 3 requires the opportunity for students to (re-)explore related phenomena and problems, to stabilize their intuitive rules and to re-discover conceptual knowledge after dealing with a specific phenomenon or problem. As can be observed in Transcript 2 students will not (immediately) remember a not well established concept when being presented with a slightly changed situation. The more experienced students are the more likely will they only need few hints and also be quicker in re-constructing conceptual knowledge. Establishing conceptual understanding at level 3 also includes to integrate more and more events within one conception and to relate different concepts (dynamically) together.

The previously presented description on how students develop a conceptual understanding has primarily emerged from our more recent teaching experiments. Therefore, we have to stress that these occur in learning settings which have a "bottom-up-design" in respect to establishing conceptual understanding (see examples in Table 1). Thus, we cannot clearly state that the processes of concept formation described match students' learning in other settings, even though some of our and other classroom data indicate similar dynamics. Also, we have to stress that we can only assume how learning processes to level 3 and at that level occur because explicit conceptualizations are rare in students' activities. Therefore, the description above should, overall, be regarded as a hypothesis which needs further research in physics and probably also in other science subjects.

So far, we have described that our students mainly act and verbalize at levels 1 and 2, that is, they deal with particular events no matter of their age or prior experiences. We have also described that in comparison to younger students, students of higher grades with more experiences in physics do significantly more often construct an intuitive rule-based understanding (level 2). The processes by which students develop from a concrete to a conceptual understanding seems to be circular (see also for example Fischer, 2008), often very slow and require several repetitions, much more than are usually offered by instruction. From a conceptual change perspective this result is either artificial (because of our distinction) or frustrating. We, therefore, would like to stress that:

A) Assuming that "missing" conceptions are either missing because they are not (yet) established or are missing because they are currently not explicitly constructed as conceptions, is probably not very popular. Rather, conceptual change research typically assumes that almost all activity is based on conceptual knowledge (Chi, 2008; Vosniadou, 1994). In an earlier study we already developed some theoretical arguments why we do not agree with the idea of conceptual knowledge being a prerequisite of any student behavior (for more details see v. Aufschnaiter, 2006a). We would like to stress that the idea of mental entities or concepts which are seen as the initiator of students' activities weakens the differences we find in what students say and do. On a conceptual basis, no matter whether students reach level 1, 2, 3, or above, activities with a similar content would refer to the same conception. Thus, this kind of progress in students' understanding is not assessed.
B) Researchers who agree with our distinction might be frustrated by the small number of explicit conceptions we identify empirically. Rather than

being frustrated we would argue that "good" intuitions in a topic are very valuable. If students have grasped an idea of how to express phenomena correctly – even if they do not really know why it is correct – and how to work on a wide variety of scientific problems successfully – even without really knowing why the chosen approach is successful – they are already on their way to develop an explicit conceptual understanding. Furthermore, our results pose a challenge to instruction. It has to be accepted that conceptual knowledge itself and not just changing this knowledge is demanding for students, no matter if conceptions are correct or incorrect. Thus, we cannot simply inform students about appropriate concepts by one or two examples (see also below) and then expect that these students understand the concept's generalizing character. Rather, we have to put lots of effort into creating appropriate experiences (systematically arranged phenomena, problems, etc.) to help students to establish intuitive and explicit rule-based understandings. From our work on the development of study material we know that the design of such material is very demanding and time consuming.

Phenomenon-based and model-based concepts

Even though the amount of explicit conceptions is small in our data, we found a noticeable difference between students' conceptions which also applies to physics concepts. Table 2 indicates two different groups of concepts. The left column refers to concepts that can be derived from experiences (observations on what can be heart or felt, how people express things, how to work on problems). We label these concepts as "phenomenon-based concepts".[4] The right column, in contrast, includes concepts which cannot be inferred directly from experiences. Rather, one has to construct a (theoretical) understanding of the principles that explain phenomena and phenomenon-based concepts ("why…"). We label this group "model-based concepts" even though this notion may cause some misunderstandings. If students, for instance, observe atomic models which are presented in a picture, on a computer screen or as a real model (e.g., illustrating atomic bonding), and then generalize that atoms are always round and have a color (which is incorrect but conceptual) we would assign this to a phenomenon-based concept as students have experienced (observed) the features over which they generalize.

Our data indicate that phenomenon-based conceptions occur (slightly) more often than model-based conceptions and seem to be less demanding for students (compared to model-based conceptions). However, due to the small number of explicit conceptualizations we still lack clear criteria to distinguish these two types of concepts in students' verbalizations. For such distinction it is also very important to hold a 2nd order perspective to reveal how a student conceptualizes a particular aspect. Especially, if students know and conceptually apply specific phrases such as "Batteries need to supply enough energy for any electrical device." we have difficulties identifying whether these phrases refer to a phenomenon-based understanding (a conceptual understanding of how to phrase things) or to a model-based understanding of the concepts involved into that phrase (e.g., the meaning of energy). Our impression from observations in schools is that students fairly quickly grasp explicitly or intuitively how to "say things right" without having (fully) grasped the model-based concept that they communicate. Teachers, in contrast, tend to assume that students who express model-based conceptions correctly have also understood their meaning.

Conclusions: Misconceptions and missing conceptions

Distinguishing between different qualities of conceptual understanding and between phenomenon-based and model-based conceptualizations as well as considering processes of concept formation offers insights into students' misconceptions. Some (mis-) conceptions occur as a result of students repeated experiences with phenomena of their everyday world. For instance, students who assume that in order to see an object one has to look at it have experienced for several times that one cannot see anything that is on the back of one's head. Assuming that metals are colder than, for instance, wood is a result of the sensory experience: usually they *feel* colder. Students' everyday experience with cycling, pushing objects, and similar activities is, indeed, that they have to exert a (constant) force to get a steady speed for any linear motion. These kinds of (mis-)conceptions are correct in a way that they refer to correct experiences students make and which are then generalized to intuitive rules and explicit conceptions. However, they also indicate which experiences are not yet (fully) present to the learner. Students have not experienced that almost all objects give off light (and this is, indeed, difficult to experience because for most objects this cannot be seen); they have not measured the temperature of different objects and compared this to their experience of these objects feeling differently warm (see also Table 1); and they have not grasped that there is a force which hinders movement (friction) and which they have to compensate for any object to move at steady speed. Thus, some of students' misconceptions explicitly point to misleading or missing experiences which, in turn, have to be made during instruction.

We conclude from our results and observations in classroom settings that all model-based concepts are difficult for students. These are, for instance, force and energy and their distinction as well as the distinction between energy, voltage, and current. As soon as students are asked about their ideas on model-based aspects, students typically either express that they don't know or they try to transfer experiences to that particular topic. Again, the effort to utilize everyday experiences creates misconceptions, such as the idea that atoms have similar properties as macroscopic objects. Unfortunately there seems to be no direct way to address model-based concepts. Either students lack any conceptual understanding or they refer to phenomenon-based ideas. Rather than approaching model-based concepts directly (for example, by contrasting these to students' ideas) we assume that a thorough analysis is needed which phenomenon-based concepts have to be established in advance of related model-based concepts. In order to, for instance, establish some conceptual understanding of the model-based concepts of electric current and voltage students should be exposed to extensive and systematical measurements of something being labeled as current and voltage so that they can discover that there are two different parameters in electric circuits that behave in particular ways. (In advance of this, students need to be able to distinguish and set-up serial and parallel circuits and mixtures of both which most of our university students cannot at the beginning of their studies. Also, they need phenomenon-based conceptual understandings of the phenomena that occur in different electrical circuits with different electrical devices (lamps, motors, LEDs, bells, …) and different power supplies. Again, our university students typically lack systematic ideas about these phenomena.) When having grasped phenomenon-based concepts about measures of current and voltage in different circuits and under different conditions it is more likely that students can and will understand (slightly) what these two concepts "mean" and why measures behave in specific ways.[3]

Instruction and teacher education

Considerations and results presented so far have considerable impact on how to design instruction and on teacher education. A detailed elaboration on both issues would require another two papers and can, therefore, only be described very briefly here.

Designing instruction

For the design of instruction, we plan the instruction from the end to the starting point of students' process of concept formation:

(1) Content to be taught is analyzed first in terms of its phenomenon- and model-based concepts. Even though different approaches towards designing instruction stress that such an analysis is important, the focus is typically on model-based concepts. In contrast, we put special emphasis on phenomenon-based concepts because these are easier to grasp for students and seem to provide the basis for any further model-based conceptualization.

(2) Documented students' misconceptions (e.g., Duit, 2009) about the topic to be taught are considered. We analyze these conceptions in terms of underpinning experiences and which experiences probably lack for an appropriate understanding of corresponding physics concepts. Also, an interrelationship to step 1 is created: Which concepts will students most likely establish because they have some matching experiences already? Which concepts are not considered? Thus, like other approaches we stress the importance of inclusion of students' misconceptions into instruction. However, our approach refers to these in order to *design* instruction rather than discussing them explicitly in the classroom (aiming to "contrast" students' misconceptions with scientific concepts).

(3) Typically, not all concepts noted in step 1 are included (extensively) into instruction (some are too difficult, some are established with students already or can be established relatively easily, some are not really required, etc.). For those included, an order is fixed (in accordance with analyses of step 2) and appropriate experiences to establish them are trialed.

(4) Study material and corresponding experiments are fixed focusing on variances and in-variances needed for students to establish an intuitive-rule based and an explicit rule-based understanding. Additional information to promote students to stabilize their ideas is prepared.

(5) In addition to step 4 examples and problems are constructed that help students to re-discover conceptions established before. These examples and problems are included into further study material which aims to establish expanding or additional conceptual understanding (e.g., Table 1).

Overall, our ideas on how to create instruction are not new. Similar ideas are, for instance, described in the Model of Educational Reconstruction (e.g., Duit, Gropengießer, & Kattmann, 2004) or with the design tool of learning demand (Ametller, Leach, & Scott, 2007). Also, conceptual change approaches stress to take scientific concepts and students' prior conceptions into account for the design of instruction. However, our impression is that no matter of the specific approach towards designing instruction and teaching (for example social constructivist, inquiry-based, context-specific) typically a small number of "good" (convincing) examples is either used to establish (inductive approach) or demonstrate (deductive approach) a scientific concept. Thus, the number of examples and the opportunities to re-discover conceptual knowledge are usually so small that students are most likely able to learn how they have to talk about these examples correctly but will only rarely build up conceptual understanding about the concepts that are to be established. Also, instruction too often focuses directly on model-based concepts by asking "why-questions" before students really know what phenomenon-based rule is to be explained.[5] As a result of experiments which do not systematically create appropriate experiences and help students to focus on these experiences, teachers often need to interrogatively find out about the conception or at least the relevant phenomenon from their students. This is demonstrated by the following Transcript 3 in which a teacher (probably) wants to establish finally that electricity can cause heat. Obviously, students have not noticed that there was some heat, let alone that the preceding experiment "demonstrated" a concept:

T: Do you remember the electric bell?

C: Yes! [in chorus]

T: OK! Did any of you notice, did any of you actually hold on to the bell after it had…been working? What did you notice?

S: Vibration.

T: Well, the arm vibrated, yes. Sound. What else did you notice?

S: It was loud.

T: That's not quite what I'm getting at. Remember the bell. There's the bell [holding up a bell in front of the class]. You did the experiment. If you held on to this bit here where the wires were [indicating], did you notice anything there?

S: There were sparks there.

T: Did you notice some heat?

S: There were sparks from there.

T: There were?

S: Sparks.

T: There were some sparks, yes. Let's just ignore the sparks a minute…some heat. There was a little bit of heat there with that one.

Transcript 3. Classroom discussion about an electric bell (from Mortimer & Scott, 2003, p. 35).

Stressing the importance of students' experiences is not entirely new. However, how much these experiences matter and how important it is to arrange them systematically in order to promote concept formation seems not to be implemented in science instruction yet (see also Marton & Booth, 1997; Marton & Pang, 2006). As a result of this, we are typically not able to understand why students often fail to grasp "simple" concepts offered and accept that the development of scientific concepts is a gradual and (very) slow process especially for model-based concepts.

Teachers as learners

It can be assumed that for prospective teachers, science education issues are as new as, for instance, physics for pupils. Like pupils in physics, prospective teachers typically hold misconceptions about teaching and learning which they have mostly developed from their experiences as pupils at school. If this assumption is valid than we can expect prospective teachers' learning processes about educational issues to be similar to pupils' learning processes in physics. Therefore, prospective teachers have to explore educational examples systematically in order to establish at least an intuitive understanding of appropriate (phenomenon-based) concepts about learning and teaching. They need to express these concepts explicitly and have to have the opportunity to re-discover them with similar examples and problems before they are able to use these concepts to plan their instruction and will understand model-based explanations. Subsequently, we can expect that teachers are able to "activate" their conceptual knowledge while teaching. Hence, the common experience that teachers do not connect theory to practice might be a result of our teacher education. Typically, we inform teachers about theory and expect them to transfer this theory into practice. With respect to the results on students' processes of concept formation we should develop theory from practice rather than expecting that teachers can "simply" be informed successfully about theory. Using just a few "good" examples to demonstrate concepts about science education will, similar to students, result in teachers learning the appropriate descriptions without understanding them conceptually: "Whenever I am asked about constructivism, I have to answer XY" (this would be a phenomenon-based conception about phrasing rather than a model-based understanding about constructivism).

Again, it seems fairly trivial to conclude that teacher education requires appropriate examples. As also discussed above, our impression is that the amount of specific examples and the way these have to be structured is by and large underestimated in teacher education. To be a little provocative, our experience with teacher education is sometimes that there is almost no connection between what is taught and how it is taught.

Summary

The main idea communicated throughout this paper is to distinguish between non-conceptual understanding (which we labeled as explorative and intuitive rule-based approaches) and conceptual understanding (which we labeled as explicit rule based-approach). Rather than focusing solely on students' ideas being correct or incorrect, these qualities together with the distinction between phenomenon-based and model-based concepts provide a powerful framework for the analysis of students' learning processes and the demands of instruction (see also v. Aufschnaiter, 2006a; v. Aufschnaiter & v. Aufschnaiter, 2007). As the distinction has to be applied to students' content specific activities but does not include content specific descriptions in itself, it can be used in different topics and (probably) in different subjects.

On the basis of our findings we have argued that conceptual knowledge is a result and not an initiator of (learning) activities and, thus, that students' prior experiences promote and hinder intended concept formation. Taking our findings into account, we furthermore argue that the problem of inert knowledge (respectively the mismatch between theory and practice) might often be a result of conceptual understanding not yet established rather than not being transferred. Students, prospective teachers and teachers often either develop an intuitive rule-based understanding of how to describe specific events or develop an explicit rule-based conceptual understanding of when to say what but do not grasp the content of the scientific concepts they can talk about.

Despite our findings, further research on that topic is needed. For instance, the following research questions still remain to be worked on:

- Is there any instruction resulting in (much) more explicit conceptualizations than reported in this paper?
- Can the distinctions be applied successfully to other science subjects?
- Which kind of conceptual quality do students incorporate into their argumentations (see also v. Aufschnaiter, Erduran, Osborne, & Simon, 2008)?
- Does the development of a conceptual understanding about the nature of science and about scientific inquiry follow similar processes?
- What kind of impact do different approaches towards teaching (dialogic vs. authoritative, constructivistic, inquiry-based, etc.) have on students' situated conceptual understanding?
- Is the assumption valid that teachers' learning processes about educational issues can be described similar to students' learning processes in physics?

Finally, we have to notice that almost everything presented in this paper refers to phenomenon-based conceptions which we have developed from our thorough analysis of students' learning processes. Even though we agree that model-based conceptions are important in our field (and have presented some of these for neuro-cognitive arguments, e.g., v. Aufschnaiter & v. Aufschnaiter, 2003a), we would also like to stress that improved phenomenon-based conceptions about the mechanisms of teaching and learning provide a powerful basis for any further educational research. Furthermore, they offer the possibility for theory formation aiming to explain why we identify specific rules about the mechanisms. Thus, all research questions presented above seek to explore in detail the phenomena occurring while learning and teaching.

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Notes

[1]*Any moving camera requires a camera person behind the camera. Our experience with such a person is that he/she attracts students' attention more than a fixed camera. This is the reason why we set our cameras up in advance of any video-recording. These cameras already record when students enter the room and the recording is stopped only when students have left the room. Thus, the cameras very quickly become some sort of furniture typically only attracting students' attention when they are bored, frustrated, or very satisfied (i.e., need to express some emotions).*

[2]*The reason why we are not stating that this is an implicit understanding (according to Rittle-Johnson, Siegler, & Alibali, 2001) is our idea of the meaning of the term "implicit". In our understanding "implicit" refers to something that is already "there" and is obvious to an observer. "Intuitive" in our understanding stresses a little more how the understanding is created rather than that it is already located somewhere. However, we are well aware that in some research projects "intuitive" is used for knowledge developed outside school contexts (e.g., Sherin, 2006), which does not match our meaning.*

[3]*We have trialed similar approaches in our content specific pre-service teacher education. Typically, students express that this is the first time they really "understand" electric circuits. However, it is obvious that the dynamic interrelationship between the set-up, included resistors, measures of current, and measures of voltage is at any level difficult for students. They often fail to connect three or more parameters in one line of thought and have then problems in approaching a phenomenon appropriately.*

[4]*The "p-prims" described by diSessa (1993) are probably either intuitive rule-based or explicit rule-based phenomenon-related ideas (which concurs with the notion of "phenomenological primitives").*

[5]*Such as asking questions like "Why is the sea salty" before students have established an understanding that the sea is salty (probably a common experience to a large number but not to all students), that not all seas are (similarly) salty, what is different between these seas and so on (see, SAC, 2008).*

APPENDIX 1. Brief coding schema on students' (conceptual) understanding

Main categories	Subcategories *Students…*	Description	Example (heat transfer)
explorative approach	act/ experiment	Students explore phenomena, e.g. carry out an experiment or measure a value. In addition, students can simultaneously describe their activity. [Just watching, reading or writing is not coded.]	(student touches an iron cube) "Touch this iron cube. It's cold."
	describe with visual aid	Students observe objects, events or situations and describe them.	(student looks at the thermometer) "The temperature is increasing."
	describe without visual aid	Students describe objects, activities or situations without observing them. Also: Students make a guess what will happen.	[student remembers:] "The water got colder."
intuitive rule-based approach	assume	Students make an assumption about what will happen. Students emphasize an aspect that is important from their point of view.	"The cold water in the petri dish will certainly reach 22 degree."
	attribute	Students make use of specific linguistic elements (particularly Physics terms) to label and describe phenomena and objects.	"This hot gel pack is a heat source."
	explain	Students explain how different concrete aspects, phenomena or situations relate to each other.	"This gel pack didn't cool down because it's wrapped in a newspaper."
explicit rule-based approach (conceptual)	generalize	Students express a generaliztion explicitly. They formulate a rule-based relationship.	"Objects adapt to the temperature of the environment."
	explain rule-based	Students use generalisations or rule-based relationships in order to explain a particular or general situation.	"This rod is at room temperature because objects adapt to the temperature of the environment."
	predict rule-based	Students explicitly refer to generalizations or rule-based connections when predicting the progress of a particular or general situation (e.g., the result of an experiment).	"The white sheet of paper won't get that warm because light and bright surfaces reflect thermal radiation."

Note. This schema is a shortened version of the German coding manual (Rogge, in prep.). This manual as well as the schema are still under revision