# Fostering conceptual change in chemistry classes using expository texts

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# Abstract

Good chemistry instruction includes the consideration of alternative ideas of students and the integration of self-directed learning activities. These learning activities require quality, student-appropriate textual material. Texts which support students in their learning path from alternative to scientific ideas are called conceptual change texts. This thesis is concerned with the question of how conceptual change texts can be designed in order to improve chemistry instruction. Three studies were conducted in this context. The first study, a survey of 240 German chemistry teachers at the Gymnasium level, showed that texts are seldom used in the classroom of secondary level I, and that texts are mainly used for revision, often at home. The study also demonstrated that textbooks are an important resource for the lesson planning of teachers. In the second study, texts on the introduction of the particle model found in two popular textbooks were analyzed qualitatively. The analysis revealed that principles of conceptual change instruction are not sufficiently taken into account for the design of texts. For the third and main study, general framework criteria for the design of conceptual change texts for chemistry instruction were compiled based on the results of the teacher survey and on principles of text comprehensibility and conceptual change instruction. Content-specific criteria for the design of a text on the particle model were developed using cognitive approaches to conceptual change as well as specific instructional approaches. A text was designed according to the criteria and evaluated in a study with 214 seventh and eighth graders. It was found that the developed criteria can be used effectively for designing expository chemistry texts. Overall, the conceptual change text yielded improved results as compared to a traditional text. It supported students in becoming aware of alternative ideas and it was overall assessed as comprehensible and interesting by the students.

# Kurzfassung

Guter Chemieunterricht beinhaltet die Berücksichtigung von alternativen Schülervorstellungen und die Integration von Aktivitäten, die das selbstgesteuerte Lernen der Schüler/-innen unterstützen. Eine notwendige Voraussetzung für solche Lernaktivitäten ist die Bereitstellung qualitativ hochwertiger, schülergerechter Textmaterialien. Texte, die Schüler/-innen auf ihren Lernwegen von alternativen zu wissenschaftlichen Vorstellungen unterstützen, werden als Konzeptwechseltexte bezeichnet. Die hier vorgestellte Arbeit beschäftigt sich mit der Frage, wie Konzeptwechseltexte für eine Verbesserung des Chemieunterrichts gestaltet werden können. Zur Untersuchung dieser Fragestellung wurden drei Studien durchgeführt. Die erste Studie, eine Befragung von 240 Chemielehrkräften an deutschen Gymnasien, ergab, dass Texte selten im Unterricht der Sekundarstufe I eingesetzt werden, und dass sie hauptsächlich zur Wiederholung verwendet werden, oft in den Hausaufgaben. Die Studie zeigte weiterhin, dass Schulbücher eine wichtige Quelle für die Unterrichtsvorbereitung der Lehrer/-innen darstellen. In der zweiten Studie wurde eine qualitative Inhaltsanalyse von Texten zur Einführung des Teilchenmodells aus zwei populären Schulbüchern durchgeführt. Die Analyse ergab, dass Prinzipien der Konzeptwechselinstruktion nur unzureichend bei der Entwicklung von Texten berücksichtigt werden. Für die dritte und zentrale Studie wurden allgemeine Rahmenkriterien für das Design von Konzeptwechseltexten für den Chemieunterricht auf Basis der Ergebnisse der Lehrerbefragung sowie Prinzipien der Textverständlichkeit und Konzeptwechselinstruktion zusammengestellt. Inhaltsspezifische Kriterien für das Design eines Textes über das Teilchenmodell wurden unter Verwendung von kognitiven Konzeptwechselansätzen und spezifischen Unterrichtskonzepten entwickelt. Auf Grundlage dieser Kriterien wurde ein Text konzipiert und in einer Studie mit 214 Siebt- und Achtklässlern evaluiert. Die Ergebnisse zeigen, dass die Kriterien effektiv für die Entwicklung von chemischen Lehrtexten genutzt werden können. Der Konzeptwechseltext erzielte insgesamt besser Ergebnisse im Vergleich zu einem traditionellen Schulbuchtext. Er unterstützte die Schüler/-innen darin, sich über Fehlkonzepte bewusst zu werden, und er wurde insgesamt von den Schülerinnen und Schülern als verständlich und interessant bewertet.

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# Contents

# 1

# Introduction

During the last years, there has been an increasing interest in Germany in improving chemistry instruction at the school level. International studies, such as TIMSS or PISA, indicate that German science classes need to focus more on preparing students to solve complex problems, particularly with the help of mental models (e.g., Baumert et al. 2000, Rost et al. 2004). Regarding the interest of students in chemistry classes, a recent survey by Sasol (2004) showed that chemistry and physics are the most unpopular subjects at school. Especially girls seem to prefer other subjects to chemistry (Kipker 2001).

To address these problems, a more student-centered instruction is needed which focuses on problem solving and on the application of scientific knowledge (Gräsel & Parchmann 2004, Prenzel et al. 2001).

## Student-centered instruction

Gräsel & Parchmann (2004) argue that an integration of situated and self-directed learning is promising for improving chemistry instruction. Situated learning approaches are based on three main assumptions (Gräsel & Parchmann 2004, p. 173):

1. Learning is an active process, i.e., learners construct their knowledge by themselves on the basis of their prior knowledge.
2. Learning is a situated process, i.e., the situation in which learning occurs influences what is learned and how it can be transferred to new situations.

3. Learning is a social process, i.e., individual learning processes are dependent on the code of practice of the respective learning group.

Characteristics of learning environments following this approach are the use of multiple authentic contexts that are relevant for students and that are related to their everyday lives, the integration of self-directed learning activities, and a focus on cooperative learning. "Chemie im Kontext" is an example for an instructional approach which has been developed according to these principles and which is currently being implemented in schools all over Germany (Gräsel & Parchmann 2004, Parchmann et al. 2001).

Self-directed learning requires that students are able to independently work with different kinds of information sources such as science books, experimental procedures, or the Internet. A focus on developing these competencies is also pivotal for educating students to become lifelong learners. However, the quality of the textual material that students are supplied with appears to be an important factor for the success of self-directed learning (Dubs 1995). Thus, for improving chemistry instruction it is important to investigate how adequate chemistry texts can be designed and integrated effectively into the classroom.

Situated learning approaches are based on a constructivist view of learning, i.e., students' individual ideas are seen as the basis for further learning. A stronger consideration of students' ideas is thus another challenge that science classes have to work on.

## Students' ideas

The constructivist view of learning regards knowledge acquisition as an active, goal-oriented process. The learner's prior knowledge influences which information the individual perceives and how the information is interpreted. For learning with understanding it is therefore necessary that chemistry instruction ties in with students' prior knowledge and thus also with their individual ideas about chemical concepts. These ideas might be brought into the classroom or they may develop under instruction. In many cases the ideas of students are not consistent with the scientific view and are therefore called "misconceptions" or “alternative ideas”. Failure to address these ideas is regarded as a major source for the often observed learning difficulties in science (Duit 1995*a*, Treagust et al. 2000). Negligence of students’ individual ideas seems also problematic from a motivational perspective. The consideration of common alternative ideas needs thus to be an integral part of the design of curriculum materials, lesson planning and teaching practice itself.

## Main research questions

The work presented here is concerned with the question of how chemistry texts can be designed in order to support students in their learning path from alternative to scientific ideas.

## Outline

We begin in Chapter 2 by summarizing basic aspects of conceptual change research. The constructivist view of learning, theories of conceptual change, and the notion of concept are discussed. We close the chapter by summarizing some strategies for fostering conceptual change.

In Chapter 3, we look at the function, use, and comprehensibility of German chemistry textbooks and outline basic aspects of research on text processing. Text features which support the comprehensibility of texts are presented and the special genre of conceptual change texts is discussed.

Chapter 4 briefly discusses models in science classes since the particle model is chosen as subject for the text which is developed in the third study. The first part of the chapter is concerned with models in general. The notion of scientific model is introduced, common ideas about the nature of models are discussed, and implications for instruction are presented. In the second part of the chapter, a simple particle model is presented along with common ideas about this model. The chapter closes with some implications for teaching the particle concept.

The next three chapters present results of studies on the use, quality, and improvement of texts for chemistry instruction.

For developing quality textual material for teaching practice it is important to know how texts are actually used in the classroom and what aspects of current textbook texts need to be revised from a practitioner's point of view. In Chapter 5, we thus investigate how texts are used in the chemistry classroom, how satisfied chemistry teachers are with current textbook texts, whether there are differences among the teachers concerning this aspect and what teachers suggest for the improvement of textbook texts. The results of a survey of 240 chemistry teachers from German Gymnasiums are presented and discussed.

Addressing of students' ideas in textbook texts is not only important with regard to the function of textbooks as learning aids for students, but also with regard to their function as teaching aids for teachers. Chapter 6 is thus concerned with the role of textbooks for the planning of chemistry instruction as well as the representation of students' ideas in chemistry textbook texts. Concerning the first aspect, the teachers in the survey described above were asked about the relevance of textbooks for the preparation of their teaching. Concerning the latter aspect, texts on the introduction of the particle model found in two popular textbooks are analyzed qualitatively.

The results of the preceding chapters are used in Chapter 7 where a multidimensional approach for the development of a conceptual change text is presented. General framework criteria for the design of conceptual change texts for chemistry instruction are compiled based on the literature reviews and on the results of the teacher survey presented in the two preceding chapters. We develop content-specific criteria for the design of a text on the particle model using results from cognitive and instructional approaches to conceptual change. A text according to these criteria is written and evaluated in an empirical study with 214 German Gymnasium students.

The thesis closes with a summary in Chapter 8, some open questions and recommendations for using the results of this work for professional development.

# 2

# Conceptual change

## 2.1 Introduction

When entering science classes, students have already gained a plethora of everyday experiences and developed various ideas about scientific issues. These pre-instructional ideas influence profoundly how further information about a specific topic is perceived and interpreted (e.g., Sumfleth 1992, Vosniadou 1994). For science, many of such pre-instructional ideas have been identified (see Duit 2006). However, a large proportion of these ideas is not consistent with the accepted scientific view. For example, children often believe that substances can change their properties while remaining the same substance ("copper becomes green") and some assume that matter vanishes when an object is burnt. For emphasizing the conflict with the scientific perspective, the notion of misconception is often used instead of more neutral terms such as pre-instructional ideas, alternative ideas or students' ideas. In the following, any of these notions is used to refer to ideas of students which are not conform with the scientific view. These ideas may have been developed in everyday life or under formal instruction.

A non-addressing of students' alternative ideas can entail learning difficulties and impede the development of scientific understanding (e.g., Duit 1995*a*, Sumfleth 1992, Treagust et al. 2000). A major task of chemistry classes is thus to help students in building a bridge from their alternative ideas to the scientific concepts. Dealing with misconceptions in practice has been revealed to be highly intricate, though. Students' ideas have shown to be strongly resistant to change (e.g., Barke & Harsch 2001*a*, Driver et al. 1985*b*, Duit 1999). Even if students seem to have accepted and understood the scientific concept, they often return to their initial concepts after having finished school.

Learning paths from misconceptions to scientific concepts are called “conceptual change processes” or just “conceptual change”. A conceptual change process is seen as a learning process in which “conceptual structures ... have to be fundamentally restructured in order to allow understanding of the intended” content (Duit & Treagust 2003, p. 673). In contrast to the beginning of conceptual change research, it is now widely agreed that conceptual change should not be regarded as an exchange or replacement of ideas but as the development of metaconceptual understanding (Duit 1999). This includes the development of metaconceptual awareness, i.e., students know different concepts and they are aware of the strengths and limitations of the concepts. Additionally, they develop the ability to apply the different concepts appropriately according to the respective context.

Research on conceptual change has its roots in two rather independent traditions, namely cognitive science and science education (Vosniadou 1999). Both domains produced many results separately, but the necessity of collaborative research has become more and more apparent. The range of investigation on conceptual change is comprehensive and widespread in both fields. In the following, some major results are outlined.

The assertion that students’ ideas are pivotal for learning is based on the assumption that learning is an active, goal-oriented construction process. Some aspects of the constructivist view of learning are thus presented in Section 2.2. Following, three theories of conceptual change are discussed (Section 2.3). In this context, the question is raised of what actually changes in conceptual change. We therefore shortly turn to the controversial use of the notion of concept. The fourth part (Section 2.4) of this chapter deals with instructional strategies for promoting conceptual change.

## 2.2 The constructivist view of learning

The constructivist view of learning assumes that each individual constructs his or her knowledge actively from his or her own experiences. This process is based on and constrained by the already existing knowledge (Widodo & Duit 2004). This condensed summary has important implications for instruction (e.g., Siebert 2003, Treagust et al. 2000):

- Learning is not seen as a "hand over" or intake of knowledge but as an active construction process. Thus, the student is the one who is responsible for his or her learning process. Teachers can only encourage and support the learning activity.
- Learning takes place on the basis of already existing knowledge. Thus, student's prior knowledge has to be taken into account seriously.
- Students construct their own personal interpretations and meanings of culturally imparted knowledge, of observations and experiences. Thus, the knowledge of the students cannot and will not mirror that of the teacher exactly.

Many views of constructivism have evolved within and across different fields such as science, psychology, biology or sociology. Three popular positions can be identified within this discourse: the cognitive, the radical, and the social constructivism. The cognitive constructivism assumes the existence of objective knowledge, i.e., reality is knowable to humans and can be internally represented in an accurate way. The radical constructivists, although not denying the existence of an outside world, support the epistemological view that this outside world stays hidden. Knowledge is seen as a personal construct which does not mirror "true" reality. Although the radical approach admits that knowledge is dependent on the context in which the respective experience is perceived, it emphasizes that individuals create knowledge from *individual* experiences. The social constructivism, in contrast, assumes that social interaction and the use of language form the basis of knowledge acquisition. The internalized knowledge is rather regarded as a shared than as an individual experience (see Doolittle & Gamp 1999, Siebert 2003).

Science education follows an approach which tries to build a bridge between the radical and the social position, the so called pragmatical and moderate constructivism, a term introduced by Gerstenmaier & Mandl (1995). This perspective interprets knowledge acquisition as an active construction process on the basis of existing knowledge. “The active, self-directed and self-reflexive learner is the center of attention. The idiosyncratic construction processes are embedded into the respective social context” (“Der aktive, selbstgesteuerte und selbstreflexive Lerner steht im Mittelpunkt und die ideosynkratischen Konstruktionsprozsse sind immer eingebunden in einen bestimmten sozialen Kontext”) (Duit 1996, p. 147). These assumptions form the framework for the development of constructivist-oriented learning environments which aim at implementing the moderate constructivist view into classroom settings. Widodo & Duit (2004) conducted a literature review on characteristics of constructivist-oriented learning environments for science classrooms and elaborated five main criteria:

**Providing opportunities to construct knowledge.** The learning environment ties in with students’ pre-instructional ideas in order to facilitate learning. Subcriteria (examples): Students are made aware of their learning process throughout the entire teaching unit; exploring of students’ prior knowledge, their pre-instructional ideas, and their way of thinking.

**Importance of learning experiences.** The learning environment accounts for students’ needs. Subcriteria (examples): Exploring of students’ interests, attitudes and emotions; providing of phenomena and examples from everyday life.

**Social interaction.** The learning environment provides opportunities for social interaction with the teacher and with other students. Subcriteria (examples): Exchange of ideas with other students or with the teacher; different forms of classroom management (individual work, team work, whole-class discussions).

**Support for self-directed learning.** The learning environment supports students in taking responsibility for their learning process. Subcriteria (examples): Students are encouraged to reflect on their ideas; teachers take students’ critical comments seriously and adapt their instruction accordingly.

**Nature of Science.** The learning environment provides opportunities for experiencing that the acquisition of scientific knowledge means continuous revision and further development of current theories. Subcriteria (examples): Considering of different scientific research strategies; considering of the limits of the explanatory power of scientific theories.

The moderate constructivist view and the deduced guidelines for learning environments have proven to be fruitful for learning in science (Duit 1995*b*, Widodo & Duit 2004). The implementation into daily classroom practice is still deficient, though. We will return to this issue in Section 2.4.2.

## 2.3 Theories of conceptual change

There is a plurality of approaches to conceptual change, ranging from theories of cognition to theories of socialization (see, e.g., Schnotz 1998, Schnotz et al. 1999, Stark 2002). This entails that there is no general definition of what is meant by “conceptual change”. In science education, there seems to be at least a wide agreement that the notion of conceptual change does not refer to learning processes that are based on a simple enlargement of knowledge structures, but to processes that require fundamental reorganization of knowledge structures (Duit 1999). This description reminds of Piaget’s idea of accommodation, the alteration of cognitive schemes in order for a child to adapt to his or her environment (Piaget 1969). However, in contrast to Piaget’s assumption of domain-general changes, the notion of conceptual change is used to refer to domain-specific changes (Carey 1985).

In order to describe and explain the interaction between students’ initial ideas and the way these ideas develop under instruction, Driver et al. (1985*a*) suggested using theories provided by cognitive science. Since then, the necessity for cooperation between cognitive science and science education has been emphasized frequently (e.g., Duit 1999, Vosniadou & Ioannides 1998). In this section, three theories of conceptual change are presented which are prominent within science education, namely the approaches of Vosniadou, Chi and diSessa. All three theories can be characterized as cognitive approaches. The focus is on the individual’s cognition, i.e., conceptual change is seen as a process which happens in the mind of an individual learner. Since the approach of Vosniadou seems to be the most promising for explaining the formation of misconceptions investigated in the main study (see Chapter 7), it is presented in more detail.

### 2.3.1 The framework theory approach

In the context of learning elementary physics, Vosniadou & Brewer (1992) developed a theory intended to explain the process of conceptual change and the occurrence of misconceptions. The approach has been further developed by Vosniadou (1994) and it has also been applied to other domains such as mathematics and religious education (Pnevmatikos 2002, Vamvakoussi & Vosniadou 2004, Vlassis 2004). Since the notion of "theory" is used within this framework for underlying mental knowledge structures, we will refer to Vosniadou's theory as "approach" or "framework" to avoid confusion.

Roughly speaking, Vosniadou's (1994) approach assumes that concepts are embedded into comprehensive theoretical structures which constrain the process of knowledge acquisition. Vosniadou (1994) discriminates between naive framework theories and specific theories. Framework theories consist of so called presuppositions which are defined as fundamental ontological and epistemological assumptions about the physical world. Examples for presuppositions are assumptions about physical objects that are built in earliest childhood. For instance, only some months old children already assume that inanimate objects do not move by themselves or that objects fall down without support (see Berk 2005, Bransford et al. 2000*a*, for a review). Such deeply entrenched assumptions are thought to frame the interpretation of further observations and culturally imparted knowledge. These interpretations result in beliefs constituting specific theories which build and structure the conceptual domain in which the respective concepts are embedded. Vosniadou (1994, p. 48) gives the following example for clarifying the difference between framework and specific theories: " ... 'hotness can transfer from one object to another which is less hot by direct contact' is one of the beliefs of a specific theory of heat transfer. This belief is constrained by the underlying presupposition that 'hotness is a transferable property of physical objects'..." The beliefs forming specific theories can be seen as second-order constraints for learning processes. In comparison to presuppositions the change of beliefs is assumed to be easier.

Another pivotal aspect of Vosniadou's approach is the construction of mental models (Vosniadou & Brewer 1992). Mental models are defined as mental representations which are structurally analogous to the object they represent (Vosniadou 2002, p. 354). Vosniadou (2002) assumes that in most cases mental models are constructed on the spot. The construction process is regarded as constrained by the individual's framework theories and specific theories. Additionally, it is presumed that mental models are designed in a way so that they are best suited to deal with the specific problem under consideration. Further assumptions about mental models are that they can be investigated by the individual in order to deduce explanations and predictions, that they themselves constrain the interpretation of new information, and that they act as mediators through which new information enters the knowledge base. Vosniadou (1994) proposes that when students learn about something which conflicts with a piece of information that has already been integrated into the knowledge base, children often succeed in reconciling the conflicting pieces by generating a so called synthetic model.

The idea of synthetic models was developed in the wake of a study of Vosniadou & Brewer (1992) who analyzed children's concepts of the shape of the earth. The data collected in the study comprised children's drawings as well as their answers to generative questions such as, "If you were to walk for many days in a straight line, where would you end up" (Vosniadou & Brewer 1992, p. 542). Based on this data, the researchers deduced for each child a mental model about the earth's shape that the child was assumed to have constructed to solve the problems during the interview. The mental models were compared with each other and it was observed that all models could be classified into only a small number of categories. In other words, there seemed to be a set of "typical" mental models. Younger children often constructed a so called initial model, which represented the shape of the earth where people live on as a flat surface. This observation can be explained by assuming a presupposition of "flat earth". Older children, in contrast, used mental models that were neither conform with this initial nor with the scientific view but suggested a mixed perspective. For example, some children used mental models which represented the earth as a hollow sphere containing a plain disk inside. This observation indicated that the older children had incorporated the idea of a spherical planet without having changed the presupposition that people live on a flat earth. A mental model that represents the earth as a hollow sphere with a plain disk inside satisfies both the assumption of a spherical shape as well as the assumption of a flat surface where people live on. Thus, according to Schnotz (1996), the child's knowledge is not inconsistent as one might think at a first glance.

The theory of Vosniadou explains learning difficulties and the often observed persistence of misconceptions in that learning science means challenging deeply entrenched assumptions. For example, for building scientifically accepted mental models about the particulate nature of matter, the assumed presupposition of continuous structure has to be questioned. However, we often observe that even scientists use mental models which seem to be built on the assumption of continuous matter, i.e., the prior presupposition seems to remain active in certain situations[1]. The context dependent use of different mental models can be explained when one interprets "change of presupposition or belief" not in terms of replacement but as change of status (Hewson et al. 1998). For instance, one might presume that prior assumptions such as "continuous structure" or "flat earth" do not change on the content level. What changes is the esteem of these assumptions compared to the culturally imparted scientific assumptions. Elaborated metaconceptual awareness enables the individual to work with, e.g., the assumption of "flat earth" in daily life, knowing that this is only a limited view and only appropriate in specific situations. Therefore, fostering students' metaconceptual awareness is regarded as a crucial component for conceptual change. Another important instructional implication that can be drawn from Vosniadou's approach is that teachers should not only address apparent misconceptions but also the respective underlying presuppositions and beliefs (Vosniadou 1994).

To sum up, the idea of a gradual change from initial over various synthetic

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[1] This problem has already been mentioned briefly by Vosniadou & Brewer (1992, p. 581), who stress that after a change of presuppositions daily observations such as "the ground is flat" do not change. What changes is how the individual interprets the observation.

models to a scientifically conform mental model accounts for the fact that conceptual change is a slow and gradual affair. As Stark (2002) argues, synthetic models can be regarded as transitions to close the gap between initial and scientific ideas. The assumption of deeply entrenched beliefs that are responsible for apparent misconceptions can also explain why some alternative ideas are highly resistant to instruction. However, like any theory, this approach is based on certain simplifications and it is restricted in its range of application. Some of these limitations are discussed in Section 2.3.4.

### 2.3.2 The category approach

Chi et al. (1994) present a theory of conceptual change which is based on three assumptions. First, all entities of the world are assumed to belong to different ontological categories such as “matter”, “processes” or “mental states”. Each category divides into subcategories such as “matter” into “natural kind” and “artifacts”. This refinement results in so called ontological trees (see Figure 2.1). Categories within a given tree do not share any ontological attributes with a category of another tree. For example, while the attribute “has weight” belongs to the “matter” tree, the attribute “is an hour long” belongs to categories of the “processes” tree. The second assumption of the theory concerns the nature of scientific concepts. Many of them are presumed to belong to a category called “constrained-based interactions” (CBI), a subcategory of “processes”. Constrained-based interactions are processes which are determined by certain constraints. The existence of the process “current”, for instance, is bound to the movement of charged particles. Further characteristics of processes in this category are that they have no clear beginning or end, and that they provide no information about their progression such as “the game is half through”. The fact that constrained-based interactions are difficult to define is regarded as a reason for the difficulties in teaching and explaining concepts of this category. The third assumption refers to the learning process of children. Children are supposed to categorize concepts like heat, light or current into the matter category instead of the category “constrained-based interactions”. Conceptual change is defined as a reassignment of concepts across trees. Chi & Roscoe (2002) assume that conceptual change is difficult because

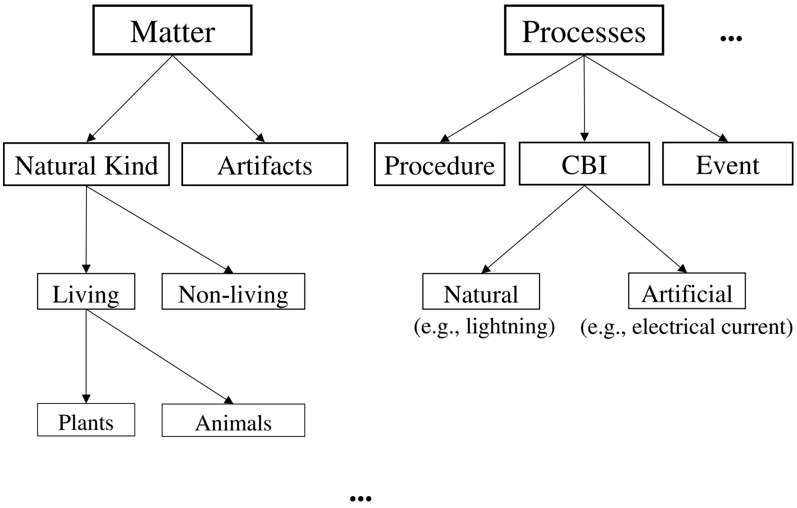

Figure 2.1: Section of a possible categorization scheme (Chi et al. 1994, p. 29).

students lack awareness of the need to "shift" a concept or because there is no appropriate alternative category available where the concept can be shifted to. However, a shift of, e.g., the concept of electricity from the matter into the processes category, is not assumed to result in a sudden and deep understanding of the concept. The shift is just seen as a first but necessary step of the learning process.

The reification of the categories as entities that one can "possess" or not has been criticized as an inappropriate simplification (Stark 2002). Since the assumed categories form the basis of the theory, Stark (2002) points out the need for more empirical evidence of their existence. A more precise definition of the categories seems also necessary with regard to the application of the theory to a wider range of topics. The limited range of applications has also been criticized by Duit (1999) who argues that the assumption of category shift cannot explain satisfactorily the learning of complex scientific concepts such as heat.

### 2.3.3 The knowledge in pieces approach

DiSessa (2002) and other researchers (e.g., Caravita 2001, Tynjälä et al. 2002) point out that in the field of conceptual change research there is still a lack of precision in the notion of concept. It is criticized that current theoretical approaches to conceptual change simply beg this question which raises the problem that – without knowing what to change – it is difficult to choose appropriate empirical methods and to develop effective instructional strategies to facilitate conceptual change (diSessa & Sherin 1998).

Additionally, diSessa et al. (1998, 2002) argue that knowledge cannot be described appropriately by only one type of mental entity as the supposed concepts. What is usually understood as a scientific concept should rather be regarded as a complex system consisting of a large number of interacting elements of varying types ("conceptual ecology" (diSessa 2002, p. 30)). From their perspective, conceptual change means modification, reorganization and combination of different mental entities in complex ways. Against this background, research should focus more on the determination of the supposed various types of mental entities. Derived from studies within the field of physics two kinds of mental entities are suggested: so called p-prims (phenomenological primitives) and coordination classes. P-prims stand for small, simple knowledge elements. Novices are assumed to have a plethora of such isolated p-prims deduced from everyday experience ("Knowledge in Pieces" (diSessa et al. 2004, p. 846)). For instance, if one pushes an object, one expects it to move in the direction of the shove. Experts, in contrast, are presumed to differ from novices in that they have integrated p-prims into comprehensive knowledge structures. This way, the atomic p-prims change their function from (primitive) explanatory elements into parts of a complex system which is more appropriate to provide elaborated explanations. With regard to the progress from naive to expert thinking, diSessa (2002) points out that metaconceptual aspects have to be taken more into account, e.g., how much students aim for coherence or how they perceive their knowledge. As a second type of mental entity, diSessa & Sherin (1998, p. 1171) propose coordination classes which are "systematically connected ways of getting information from the world." Coordination classes include at least a set of methods to select information (readout strategies) and a set of possible inferences which can be drawn from a given information (causal net). Unlike p-prims, coordination classes are assumed to be large, complex systems.

The claim for a clarification of notions within conceptual change research appears warrant. A more systemic and complex view may also reflect the actual process of knowledge acquisition better than more simplified approaches. The theory may need further elaboration concerning the determination and specification of the assumed mental entities, though, and concerning the description of the interaction between the different types of entities. The main question is, however, whether and how this theory can be expanded to other fields than elementary physics. In this context, diSessa et al. (2004) point out the problem that the Knowledge in Pieces approach has been developed with focus on domains that are experientially rich as, e.g., mechanics. They doubt that the approach can be fruitfully applied to other domains.

### 2.3.4 Summary and discussion of the theories

In summary, one can say that Vosniadou's theory describes conceptual change as a change of presuppositions and beliefs. Students are assumed to construct mental models to solve problems, and the formation of these models is supposed to be constrained by the individual's prior knowledge. When learners are confronted with a piece of information that conflicts with one of their presuppositions or beliefs, it is suggested that instead of changing the prior assumption a so-called synthetic model is formed. Such a mental model satisfies both the new piece of information and the respective prior presupposition or belief. Synthetic models thus reflect consistent knowledge. However, they are faulty from a scientific perspective and thus called misconceptions. The gradual change from initial to more elaborated concepts is presumed to be expressed in gradual changes of mental models.

Chi assumes humans to assign concepts into different categories. A wrong categorization – according to the scientific view – is called misconception. Conceptual change means reassigning concepts across ontologically different trees.

DiSessa's theory interprets conceptual change as the connection of various mental entities in complex ways. The learner has to integrate existing fragmented pieces of knowledge by reorganization and restructuring.

Although all three approaches are based on a constructivist view of learning, they take different stances to theorize conceptual change as the short summary points out. Assumptions about the structure of novices' knowledge also differ fundamentally. For example, whereas Vosniadou assumes coherent knowledge, diSessa suggests fragmented knowledge. Both assumptions have been discussed and studied for years, and as diSessa et al. (2004, p. 846) argue, "it is almost difficult to believe they both have survived empirically as long as they have." All three approaches agree, though, that the learner's lack of metaconceptual awareness is a crucial impediment for conceptual change.

In the following, some points of criticism concerning cognitive approaches to conceptual change are outlined which are well elaborated in Stark (2002). First, the research community has focused primarily on initial learning so far and neglected advanced learning, particularly in complex and fuzzy domains. The focus has been on eliciting the status quo of a learner's knowledge instead of investigating the *process* of conceptual change. Second, the conditions of knowledge assessment need reconsideration. Besides the problem of question bias, lab conditions fail to demand the distribution of cognition as it is required for problem solving in everyday life. Cognitive approaches further focus on the individual's mind and neglect the influence of emotional and motivational factors as well as the interaction between peers. The pivotal role of context for learning and problem solving has also not been sufficiently taken into account yet. Although Vosniadou & Ioannides (1998) argue that different representations of a concept may coexist and that situational variables may influence which representation is used in a specific situation, the aspect of context has not been an integral part of the framework and category approach so far. The Knowledge in Pieces approach, in contrast, does take context-based reasoning into account by assuming that beginners differ from experts by their judgment of when two situations can be regarded as isomorphic. DiSessa et al. (2004, p. 853) suggest that situations which are identical to a scientist are often very different to beginners. Thus, it is presumed that a novice uses different p-prims to reason in situations that are regarded as identical by an expert (diSessa & Sherin 1998).

The outline of the three theories of conceptual change has shown that, although the notion of concept is widely used in conceptual change research, there seems to be no common definition of this term. In the following, we therefore shortly turn to the controversial meaning of the notion of concept.

### 2.3.5 The notion of concept

The traditional view of the notion of concept assumes that humans tend to organize and categorize objects of their environment. This theory uses “concept” as a synonym for “category”. Categories are defined by certain attributes. For example, a chair might be defined as a thing with four legs, a seat and a backrest. This instance shows that the definition list may consist of more than one attribute. Here it is important to know the logical combination of the features, i.e., the structure of the category. For example, in order to learn the concept “aggression” one has to acquire the two attributes “do harm to someone” and “do this on purpose” and, additionally, one needs to connect the attributes with the logical conjunction “and” (Edelmann 2000, p. 118). In this context the construction of a new concept means to combine objects into a new category. Identification of a concept means that an individual identifies a particular object as member of an existing category (Edelmann 2000).

According to this theory, conceptual change is interpreted as individuals learning to classify objects consistent with authority (White 1994).

This so called classical view has been criticized as not describing the process of categorization in everyday life appropriately. Everyday notions are often fuzzy and the boundaries determining membership are variable which implicates that categorization requires the consideration of context. For example, a glass with flowers is rather categorized as a vase than as a drinking vessel. Furthermore, objects are not always categorized according to logical aspects but rather with regard to pragmatical issues: Once a piano is identified as a member of the category “music instruments”, another time, e.g., associated with moving, it is categorized as “heavy furniture” (Edelmann 2000).

Based on this theory, conceptual change means that an individual learns to classify objects context dependently (White 1994).

Another point of criticism concerns the assumption that an object can only belong to a certain category if it shows all determining attributes. The critics argue that humans tend to deal with concepts in a different way. For example, “ability to fly” is often used as the characteristic feature of the category “birds”, although it is not an attribute of all birds. But it applies to a member of the category with high probability and is, therefore, a useful and sensible criterion for estimating category membership in the first instance. This so called probabilistic view assumes that concepts are stored in terms of best examples which are ideal representatives or prototypes of the respective category. Determining membership means to estimate the degree of similarity between the object and the prototype (Edelmann 2000).

Besides these theories, which both stress the categorization aspect, a concept is sometimes regarded as all the knowledge a person associates with its name. Thus, conceptual change occurs whenever one learns something new about the respective concept (White 1994). This view describes a simple way of learning and is comparable to Piaget’s process of assimilation. However, the notion of “conceptual change” is, in general, rather used to describe processes of accommodation, which means not only addition but profound restructuring[2].

Similarly, the category approach does not seem to be sufficient to appropriately describe what is meant to change in conceptual change. Regarding scientific concepts, diSessa & Sherin (1998) object that within science education the term “concept” is used in a much broader sense. Even though the category approach might model concepts such as “bird” well, it does not describe complex concepts such as “number” or “heat” appropriately. This corresponds to the critic that has been mentioned in connection with Chi’s et al. theory of conceptual change.

White (1994) thus suggests using the notion of “conception” instead of “concept” to describe a more complex way of learning and not only categorization. According to his position, conceptions are systems of explanation. They are seen as more complex and difficult to define than categories. Learning a conception means more than acquiring factual knowledge, it means gaining deep understand-

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[2] A difference to Piaget’s theory is that conceptual change processes are assumed to be domain-specific and not domain-general reorganizations of knowledge structures (Carey 1985).

ing which results in the ability to apply the knowledge adequately in unfamiliar situations.

This short overview shows the ambiguity of the notion of concept. In conceptual change research there is no agreement about the word "concept". Instead, it is used quite differently in different studies (Tynjälä et al. 2002). Due to the lack of a precise definition, we use the notion of "concept" in the following in a similar way as White (1994) uses the notion of "conception". Concepts are regarded as large knowledge structures in which main aspects of a certain field are connected in multiple ways. These knowledge structures enable the individual to find explanations and solve problems within the respective domain.

## 2.4 Instructional strategies for conceptual change

Early in the beginning of conceptual change research Posner et al. (1982) suggested a theory that describes the conditions that must be fulfilled in order to bring about conceptual change. The approach is discussed in this chapter under "instructional strategies" since it has become a leading paradigm for science instruction (Section 2.4.1). In the following section, further important aspects of teaching for conceptual change are discussed (Section 2.4.2). We have already mentioned that conceptual change does not mean replacement but the development of metaconceptual awareness and the ability to apply scientific concepts appropriately according to the respective context. This issue is elaborated in more detail in Section 2.4.2. Finally, some obstacles are outlined which impede the implementation of instructional strategies into daily classroom practice.

### 2.4.1 The theory of Posner et al.

The theory of Posner et al. (1982) assumes that learning is a rational activity. In other words, humans "comprehend and accept ideas because they are seen as intelligible and rational", and the verification of these characteristics is done based on the available evidence (Posner et al. 1982, p. 212). Despite this rational focus, Posner et al. (1982) concede that motivational and affective aspects are also important factors for effective learning. However, these variables are not an integral part of their approach.

For developing a theory that defines necessary conditions for conceptual change, i.e., the change of concepts of an individual, Posner et al. went back to the philosophy of science where Kuhn and Lakatos had studied conditions for the change of scientific theories, i.e., the change of theories accepted by a scientific community. They had shown that several prerequisites must be fulfilled in order for a new theory to be accepted. Based on these results Posner et al. (1982, p. 214) deduced four conditions which determine whether a student engages in conceptual change or not.

1. *There must be dissatisfaction with existing concepts.*
2. *A new concept must be intelligible.*
3. *A new concept must appear initially plausible.*
4. *A new concept should suggest the possibility of a fruitful research program.*

First, students have to collect a pile of contradictory information and to conclude that their current concepts are not capable to explain these anomalies. In other words, they have to perceive a cognitive conflict which makes them dissatisfied with their present concepts. Second, the students have to see how the puzzling information can be structured by the new concept. Third, they have to trust in the capacity of the new concept, especially, that it can solve the problems caused by their prior concepts. Finally, the new concept should foster inquiry by opening new research areas (Posner et al. 1982).

Although the approach of Posner et al. (1982) seemed promising, it could not meet the expectations. Students' ideas do often not or only partially change under an instruction which focuses on cognitive conflict (e.g., Driver et al. 1985*a*, Duit 2002, Limón 2001).

For exploring the constraints which must be fulfilled in order to evoke an effective cognitive conflict, Chinn & Brewer (1993) investigated the question of what type of responses students may give to anomalous data. Therefor, an analysis of findings from the history of science and from empirical conceptual change research was conducted. Based on this analysis, Chinn & Brewer (1993) defined seven possible types of responses to anomalous data, only one of them reflecting conceptual change.

**Ignoring.** Students simply ignore the piece of anomalous data and they do not bother to find an explanation for it.

**Rejection.** The only difference to ignoring is that students give an explanation why the data should be dismissed.

**Excluding.** Sometimes students do perceive the anomaly, but they do not see the necessity to judge the validity of the data. They declare the data to be out of the range where the respective concept can be applied to[3].

**Abeyance.** Students decide not to deal with the anomaly at once but they hold the contradictory data in abeyance, assuming that their current concepts will someday be capable to explain the data.

**Reinterpreting.** Student accept the data as valid and as something which should be explained by their concepts. However, instead of restructuring their knowledge, students reinterpret the data so that it can be explained with their current concepts.

**Peripheral change.** Students are not willing to give up the core beliefs on which the respective concept is built, but agree on making relatively minor modifications within their knowledge structure in order to explain the contradictory data.

**Concept change.** Students response to the presentation of anomalous data by changing core beliefs and by accepting the scientific concept.

Chinn & Brewer (1998) tested the taxonomy some years later with 168 undergraduate students. The participants first read a text presenting an initial theory

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[3] Chinn & Brewer (1993) use the notion of theory instead of "concept". Theories are regarded as collections of beliefs (i.e., pieces of knowledge within the knowledge base of an individual) with explanatory power (Chinn & Brewer 1993, p. 39). This definition is similar to the interpretation of "concept" as it is used in this work, so the notion of concept is used here.

with supporting evidence. A part of the students read a text on the meteor theory of mass extinctions, the volcano theory of mass extinctions, the warm-blooded dinosaurs theory, and the cold-blooded dinosaurs theory, respectively. Afterwards, the students rated their belief in the respective theory. The participants were then given a text describing data that contradicted the initial theory. After having read the second text, they were asked to rate to which extent they believed the data, whether the data were consistent with the initial theory or not, and to which extent they now believed in the initial theory. The students were requested to explain all their ratings. The explanations were classified according to the type of reasoning that was used. Thirty-three categories of reason types were found such as "Reason for disbelief: Small data sample". Each category was then assessed according to the following three questions: "Are the data accepted as valid?", "Are the data explained?", "Is the current theory changed?". The characteristics of a category on these three dimensions indicated whether the category belonged to one of the seven response types of the taxonomy described above. For instance, a category with the sequence "No, No, No" was classified as belonging to the response type "Ignoring", a pattern of "Yes, Yes, No" to the response type of "Reinterpretation". The results of the empirical study supported the taxonomy described above. Only one response type, "Uncertainty", needed to be added in order to account for answers in which students were unsure whether the presented data was valid and trustworthy. This enlarged taxonomy was again tested and confirmed in a study with 126 eighth graders on the topics of the extinction of the dinosaurs and the construction of the Giza pyramids (Mason 2001). All responses of the students in this study could be assigned to one of the eight response types, except the category "Ignoring". However, as Mason (2001) argues, studies where students are explicitly asked to evaluate the presented data are probably not appropriate to evoke responses of the type "Ignoring".

To conclude, the presentation of anomalous data in order to provoke a cognitive conflict might entail conceptual change. However, there are many other ways how to respond to the presentation of contradictory data which do not result in the desired knowledge restructuring. It is therefore necessary to know which instructional aspects support students in accepting and understanding the anomalous data, and which motivate them for finding an explanation. We follow this aspect in Section 2.4.2.

Besides these practical problems, the approach of Posner et al. has also been challenged from a theoretical perspective. Caravita & Halldén (1994) criticize the implicit analogy of “the student as scientist”. They argue that there are main differences between the work that a scientist does within the scientific community and the work that a student does within the classroom community. For example, whereas scientists choose the subject they want to study by themselves, students are mostly given a subject to study by the teacher. Whereas scientists see the making of conjectures as a an essential part to solve problems the scientific community has not agreed upon yet, students often see the making of conjectures as a game in which the teacher already knows the answer to the problem. The goals of the scientific community and their codes of practice also differ in many aspects from those of the classroom community. The negligence of the classroom context as well as of motivational variables has also been criticized by Pintrich et al. (1993). They argue that students’ self-efficacy beliefs and their goals for learning influence the way and degree of engagement in problems and thus in conceptual change. Other researchers also cautioned that neglecting these aspects may entail that students do not take the effort of changing their knowledge structures, since the conflict is not really meaningful to them (Limón 2001).

Despite these drawbacks, a meta-analysis of Guzzetti et al. (1993) showed that the strategy of evoking a cognitive conflict is more successful than introducing a new concept without challenging students’ ideas. Limón (2001, p. 368) also reviewed the controversial results obtained by the application of the cognitive conflict strategy and comes to the conclusion that, although a unique presentation of anomalous data is not seen as sufficient for conceptual change, “cognitive conflict is a first step for any change or restructuring of students’ beliefs.” Thus, the idea of provoking a cognitive conflict by an experiment, text or discussion is generally a good starting point for conceptual change processes. However, it is only one factor of many that have to be considered by teachers when they want to create challenging learning environments.

### 2.4.2 Implications for instruction

Comprehensive teaching units have been developed in order to foster conceptual change (e.g., Duit et al. 2001, Vosniadou et al. 2001). The problem is, however, that the more is known about conceptual change processes the more complex the teaching approaches become. As Duit (2002, p. 13) argues, "the gap between what is necessary from the researcher perspective and what may be set into practice by 'normal' teachers has increased more and more..." He additionally points out the problem that the testing of strategies in actual classrooms does not guarantee that the strategy works in everyday practice. In the following, we confine ourselves to give a short overview of basic principles of teaching for conceptual change. The summary does not claim to be comprehensive or exhaustive. On the one hand, conceptual change research is a huge and multifaceted field. On the other hand, the question of what supports conceptual change goes back to the fundamental question of what supports challenging learning processes. Limón's (2001) critical appraisal of the cognitive conflict strategy illustrates well the multidimensionality and complexity of factors influencing conceptual change. Therefore, only a selection of aspects with focus on the sciences is outlined.

**Addressing of misconceptions.** For effective chemistry classes it is essential that students' ideas are taken into account (e.g., Driver et al. 1985*b*, Sumfleth 1992, Treagust et al. 2000). Therefore, teachers need to be informed about common misconceptions. This refers to general misconceptions, e.g., about the nature of science, as well as to content-specific ones, e.g., about chemical change. Otherwise, teachers and students are likely to talk at cross-purposes without learning to occur (Duit 1995*a*, Sumfleth 1996). Besides the knowledge about common misconceptions teachers need to have a repertoire of strategies at their disposal for addressing these misconceptions. A widely used strategy in chemistry classes is to challenge students' ideas by presenting experiments with an unexpected outcome. In the following, some aspects are discussed that need to be considered in this context (for a comprehensive discussion see, e.g., Limón (2001)).

When experiments are presented in science classes, students observe them through the filter of their knowledge. They tend to "see" what they expect to see according to their current concepts (Duit 1995*a*). Thus, for challenging students' ideas unambiguous experiments need to be chosen that clearly show the anomaly. Aspects that decrease the credibility of the data, e.g., methodological shortcomings, should be minimized, and general criteria for judging the credibility of data should be discussed with the students (Chinn & Brewer 1993).

An unexpected outcome is, however, not a guarantee for students engaging in knowledge restructuring. As Limón (2001) concludes, it is the meaningfulness of the conflict that is crucial, i.e., the anomaly has to be relevant for the students. One can assume that anomalies that relate to students' everyday life experiences are likely to be interesting to them. On the other hand, since humans generally have a "need to solve problems" (Bransford et al. 2000*a*, p. 102), a "pure chemistry anomaly" might also be interesting for students just for its intellectual challenge. Against this background, it seems necessary to investigate systematically the plenty of experiments that are used in chemistry classes for evoking cognitive conflicts concerning the question whether they actually rise students' interest and whether they motivate students to engage in conceptual change.

It is additionally doubted that a single contradictory experiment convinces all students. Chinn & Brewer (1993) thus suggest to present multiple experiments. Therefor, they propose two strategies. The teacher may anticipate critical responses in advance and present the respective experiments to prevent discrediting responses. Alternatively, he or she may conduct experiments ad hoc according to students' answers during classes. The latter strategy seems more appropriate for challenging science teaching, since students should not only learn content based knowledge but also the process of knowledge acquisition in science.

In order to address the actual misconceptions that the students in a specific classroom hold, teachers need to have strategies and tools at their disposal to elucidate the ideas of each individual student. The "Lernbegleitbögen" developed by Schmidt et al. (2003) seem promising in this context. The students are given everyday problems they have to comment on in written form at the beginning of a teaching unit, during the unit and at the end of the unit. They are encouraged to re-read their previous answers and to comment on them. Thus, not only the teacher gets insight into the ideas of his or her students, but the students become more conscious of their learning process, too. However, since students often have problems in putting their thoughts into written form (Nieswandt 1997), the “Lernbegleitbögen” need to be combined with other methods, e.g., classroom discussions. In general, it seems to be urgent that research dedicates more to the development of tools which reliably elucidate students’ ideas and which are easy to handle in daily classroom practice. For example, “Lernbegleitbögen” need to be developed for different age groups and for the different topics that are taught in chemistry classes. The question of how the developed tools can be transferred into the classroom on a broad basis needs to be addressed, too.

**Addressing of entrenched beliefs.** Vosniadou’s (1994) theory of conceptual change assumes that deeply entrenched beliefs constrain the way students perceive and interpret new information. Thus, in order to bring about conceptual change, those impeding beliefs need to be addressed. For example, if a teacher wants to challenge the students’ hollow-earth model (people live “inside” the hollow earth) it is not enough to provide evidence supporting the spherical model but it is necessary to address the assumption that things fall downward (Chinn & Brewer 1993, Vosniadou 1994). However, there is still research necessary in order to identify the underlying beliefs which may impede the learning of key concepts in chemistry.

**Addressing of students’ epistemology.** Conceptual change implies that students realize that a phenomenon can be explained by different concepts and that they learn to judge the quality of different concepts according to scientific standards. In other words, students’ understanding of the nature of science plays a major role in conceptual change. A lot of research has shown, however, that developing understanding of the nature of science is difficult and takes time. For example, students often make no sharp distinction between theories and evidence, they think that scientific knowledge is an exact copy of nature (e.g., Carey et al. 1989, Gilbert 1991), and that knowledge is socially constructed is often neglected in the science classroom (Driver et al. 2000). Different studies have shown that scaffolded inquiry with a special focus on metadiscussions can support students in gaining more sophisticated epistemological beliefs (Carey et al. 1989, Mikelskis-Seifert 2002, White & Frederiksen 2000). Thus, a culture of discussing different responses to contradictory data, of debating alternative concepts and comparing the strengths and limitations of the respective concepts is seen as key to conceptual change instruction. In this context, students might not only discuss their own ideas but also competing concepts from the history of science and evaluate them against the background of the knowledge at that time (Chinn & Brewer 1993).

**Caring for a safe environment.** Teaching for conceptual change is essentially based on a trusting and open classroom atmosphere. Students have to engage honestly in discussions and they have to admit difficulties and problems frankly. Therefor, they need to trust that their ideas and questions are taken seriously, both by the teacher and by their peers. They need to be confident that the community is supportive and that each student's ideas are valued (Beeth 1998, Duit 1995*a*, Mitchell 1992). This entails that the teacher establishes a culture that appreciates errors as a basis for learning and that he or she teaches students how to work with errors in a productive way (Müller & Nieswandt 1999, Spychiger et al. 1999).

**Fostering students' metacognitive abilities.** Meaningful and reflective conceptual change requires deep processing. The learner has to investigate the anomalous data carefully, has to make serious efforts to understand the new concept and has to elaborate multiple relations between the "new" and the "old" concept (Chinn & Brewer 1993). This presupposes that students are able to apply sophisticated learning strategies. They need to become aware of their current knowledge, they need to plan, control and assess their learning process. Fostering students' metacognition, i.e., "the ability to monitor one's current level of understanding and decide when it is not adequate"

(Bransford et al. 2000*b*, p. 47), is therefore seen as a crucial component for conceptual change instruction (e.g., Beeth 1998, Hewson et al. 1998). Teaching approaches which focus on enhancing students' metacognition have been developed for different subjects. In the field of mathematics, for example, Schoenfeld (1992) suggests that students should work in small groups on specific problems. The teacher observes the groups carefully and scaffolds the development of metacognition by regularly asking the students what they are exactly doing, why they are doing it, and how it helps them in solving the problem. In the field of reading comprehension, the strategy of reciprocal teaching has been developed (Brown 1994). Articles are discussed in groups and students take turns in leading the discussions. During these discussions students learn to use concrete strategies such as asking questions about the article, summarizing the gist of the article, or revealing and clarifying problems of comprehension. In the field of science education, White & Frederiksen (2000) developed the ThinkerTools Inquiry Curriculum which has the enhancement of metacognitive skills at its center. The curriculum supports students in learning how to reflect their own and other's research according to scientific criteria. Beeth (1998) also presents a teaching approach for science education where students are constantly encouraged and supported to speak about their concepts. Here again the students are asked to work in small groups and they learn to use the status constructs of intelligibility and plausibility to evaluate different ideas.

These instances show that educational research has addressed the problem of how to foster students' metacognitive abilities by providing concrete instructional suggestions for different subjects. However, the question is how a broad implementation of these approaches into daily classroom teaching can be accomplished.

**Fostering students' metaconceptual awareness.** The development of metaconceptual understanding requires that students develop metaconceptual awareness, i.e., they know different concepts that can be used to explain a phenomenon within a specific subject area and they are aware that different contexts ask for different concepts. Eventually, students should be able to apply the different concepts appropriately according to the respective context. In the first place, it seems crucial that students' become aware of their own concepts and beliefs, and of the similarities and differences between these ideas and the scientific ones (e.g., Mikkilä-Erdmann 2001, Vosniadou 1994). Therefor, they should be given plenty of possibilities for expressing their ideas, listening to the ideas of their classmates and of discussing and contrasting the different concepts (Vosniadou & Ioannides 1998). In the second place, it is important that students learn about a wide range of contexts in which the scientific concept can be applied more fruitfully than everyday ideas (Duit 1995*a*). The difficulties that may rise when metadiscussions about the context of a problem are neglected are elucidated by the well-known “Linda task”.

Kahneman and Tversky conducted a study in which students were first presented with the following information: “Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations” (Kahneman & Tversky cited in Halldén 1999, p. 57). Afterwards, they were asked to state what was more probable: “(i) Linda is a bank teller; or (ii) Linda is a bank teller, who is active in the feminist movement” (Halldén 1999, p. 57). Halldén (1999) challenges the view that all students who chose statement (ii) held profound misconceptions about the theory of probability by arguing that some of them just contextualized the problem differently than expected by the researchers. In order to investigate this aspect he replicated the study with 50 students, but he additionally asked the participants to justify their choice. The comments of the students showed that some of them were actually aware of the rules of probability, but they deliberately decided in favor of statement (ii). Some even kept to their decision after being presented with the probabilistic solution. Halldén (1999) concludes that the students classified the problem not into a mathematical context but into an everyday life context. Therefore, they did not apply statistical rules but everyday life reasoning.

This conclusion is supported by Hertwig (1996) who analyzed the task against the background of theories of communication. He points out that the task uses the ambiguous notion of probable which is not only used as a technical term in statistics but also in everyday language. In order to determine the meaning of probable in this situation one can presume that the participants relied on the assumption that the information about Linda presented in the task were relevant for the interpretation of the notion of probable. A study of Hertwig (1996) showed, however, that the personality sketch rather suggests a non-mathematical interpretation of "probability" such as "possibility" instead of the statistical meaning.

This example shows that it is not only important to offer students various contexts in which they can practice the application of a scientific concept, but that it is also pivotal to discuss on a metalevel why the respective concept seems appropriate for the given context. The development of the ability to use different concepts flexibly and appropriately takes a lot of time and experience, but it is the basis of scientific practice as Richard Feynman points out:

"The mechanical rules of 'inertia' and 'forces' are *wrong* – Newton's laws are *wrong* – in the world of atoms .... it was discovered that things on a small scale behave *nothing like* things on a large scale. That is what makes physics difficult – and very interesting" (Feynman et al. cited in Linder 1993, p. 296).

### Practical impediments

Despite the vast amount of research on the constructivist view of learning and conceptual change, science teaching in the classroom still seems to be based on a transmissive view of learning (Seidel et al. 2002, Widodo & Duit 2004).

Teaching for conceptual change is a challenging endeavor. Even if one is familiar with the constructivist view, it is not easy to translate the theoretical beliefs about teaching and learning into actual teaching practice (White 2000). In spite of that, teachers are often let alone with the implementation of new teaching approaches. This is probably the main reason for the often observed patchy and superficial integration of only some few elements of constructivist learning environments into traditional ways of teaching (Cohen 1990, Hiebert & Stigler 2000). Thus, it is not sufficient to develop new teaching approaches but it is as important to support teachers in implementing these strategies.

Additionally, many of the instructional approaches developed by educational research do not take the constraints of daily school practice into account. The strategies are often not geared to 45-minute lessons and are not compatible with overloaded syllabi (Bransford et al. 2000*c*, Limón 2001). Duit & Treagust (2003, p. 684) summarize the problem in that "it is necessary to close the gap between theory and practice at least to a certain extent. What research on conceptual change has to offer classroom practice cannot be set into normal practice to a substantial extent."

## 2.5 Conclusions

The overview of conceptual change research has shown that, despite nearly 30 years of research, many problems are still unsolved both with regard to theories describing conceptual change and with regard to instructional strategies how to promote the learning process. This is not surprising, though, since conceptual change is concerned with basic aspects of meaningful and sustained learning. Nevertheless, two main guidelines may be deduced for science teachers.

First, students' prior knowledge is the starting point for any instruction. Teachers have to inform themselves about common everyday ideas and about common misconceptions that might develop under instruction. Working with the individual ideas of the students needs to be an integral part of science teaching. Second, this teaching approach needs to be made explicit to the students. It is important to foster their metaconceptual awareness, and to regularly practice and conduct metadiscussions about different concepts and the process of knowledge acquisition.

The main challenge for conceptual change research in the future is to move on from detecting misconceptions and elaborating complex theories and teaching units to developing strategies of how to implement basic principles that have proven to be crucial into practice. Implementation must not be seen as a transmission of knowledge from researchers to teachers, but professional development courses need to adhere to the principles of the constructivist view of learning, too. The learning communities which have been formed for the implementation of the teaching approach “Chemie im Kontext” provide a promising example of how teachers and researchers can work collaboratively in order to change traditional ways of teaching (Gräsel & Parchmann 2004). Similarly, researchers from science education, cognitive science and social sciences need to work closer together in order to tackle the complexity of conceptual change research. The work on students’ ideas has shown that there are no simple recipes – neither for research nor for instruction. As Caravita (2001, p. 428) argues, ”cognitive conflict ... is considered as dependent on many psychological and personal factors that instructional intervention can only partially address and control in the classroom. Educational research can not provide recipes, but only repertoires that may help to recognize patterns in particular situations and to select tools that may prove more suitable than others, at least for some of the participants in the teaching/learning environment.”

# 3

# Texts for chemistry teaching

The work presented in this thesis is concerned with the question of how to foster conceptual change in chemistry classes using expository texts. The following chapter reviews research on text comprehensibility in general and on the special genre of conceptual change texts in particular.

The first section of this chapter discusses the function, use and comprehensibility of German chemistry textbooks texts (Section 3.1). The second part outlines basic aspects of research on text processing (Section 3.2) which is the theoretical basis for the investigation of text features which support the comprehensibility of texts (Section 3.3). The special genre of conceptual change texts is discussed in Section 3.4.

Chemistry textbooks are complex media which contain a wide range of types of knowledge representation, e.g., expository texts, instructions for experiments, pictures, tables, figures, exercises, or mathematical formulas. In the following, we focus on continuous expository texts. In contrast to discontinuous texts such as tables or graphs, continuous texts are made up of sentences which are arranged into paragraphs (Artelt et al. 2001).

## 3.1 Chemistry textbook texts

### 3.1.1 Function of textbooks

In order to assure that all German students achieve similar competencies irrespective of teacher and school, the state uses syllabi and textbooks to guide

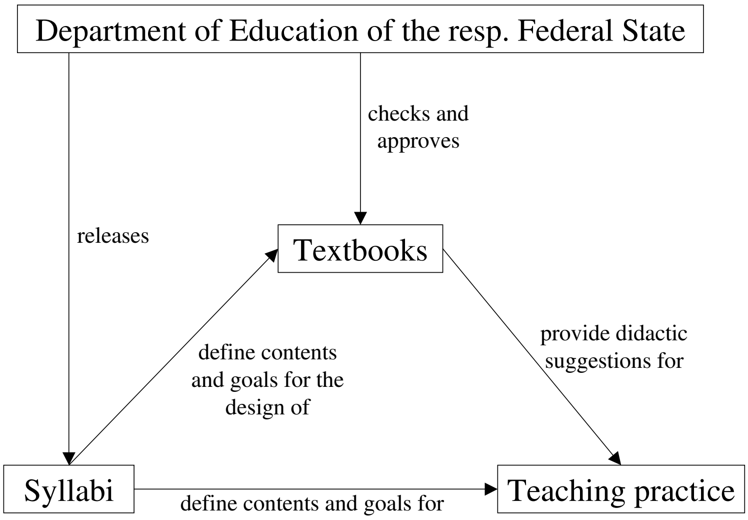

Figure 3.1: Textbooks as an interface between syllabus and teaching practice (Heinze 2005).

teaching practice. In this context, textbooks are commonly regarded as an interface between syllabi and classroom teaching (Heinze 2005). The standards that textbooks have to fulfill are challenging since they should not only "contain the knowledge that should be learned", but they should also "train the young people in developing their civil maturity and their social responsibility in public life" (Pöggeler 2005, p. 21). Figure 3.1 visualizes in a simplified way how textbooks function as an interface between syllabi and teaching practice[1].

The departments of education of the federal states of Germany release syllabi which are summaries of teaching contents and goals that have to be taught in a specific subject at a specific type of school during a specific period of time (Wiater 2005, p. 42). Textbooks need to be designed according to the syllabi in order to be approved by the respective departments of education. In specifying the often more general guidelines of the syllabi, textbooks provide didactic suggestions how

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[1] Simplifications are, e.g., the confinement to unidirectional relations and the negligence of the various other factors influencing the development of textbooks.

to translate the syllabi into teaching practice (Wiater 2005). They are thus not only used by students but also by teachers for planning teaching units and lessons (Heinze 2005).

A common type of science textbook used in Germany is a book that represents scientific knowledge by following the structure of a “typical” science lesson, i.e., motivating, presenting a problem, conducting an experiment, interpreting the experiment, stating a result, applying and practicing the new concept (Merzyn 1987). However, new approaches to science teaching such as “Chemie im Kontext” as well as the shift from syllabi with detailed, input oriented learning goals to general, output oriented standards (Bildungsstandards) which focus on different types of competency (content knowledge, epistemology, communication, assessment (Kultusministerkonferenz 2005*a*)) challenge this traditional pattern of science teaching and thus also the traditional design of textbooks (Wiater 2005).

### 3.1.2 Use and comprehensibility of textbook texts

Research on German chemistry (e.g., Becker 1980, Becker & Pastille 1988, Häusler 1987, Hermanns 1987) and physics textbooks (see Merzyn 1994, for a summary) peaked in the 1980s. In the following decade, the focus shifted to the investigation of how to integrate information and communication technology into the science classroom. One of the few current studies on physics textbooks was conducted by Starauschek (2003) and confirmed the results of the 1980s. The investigation showed that revision is still the main purpose for the use of textbooks and that students are still not satisfied with the comprehensibility of the textbooks. With regard to chemistry instruction, it is not clear how textbooks are currently used in the classroom. However, a more recent study of Schüttler (1994) was concerned with analyzing the comprehensibility of a German chemistry textbook text on detergents. The analysis revealed major shortcomings concerning criteria of text comprehensibility. Although short sentences and common words were used in the text, “the contents were presented in an either too complex, ambiguous or incongruent way” (“die Sachverhalte entweder zu komplex, uneindeutig oder inkongruent dargestellt werden”) (Schüttler 1994, p. 84). An analysis of Mikelskis-Seifert (2002) also showed that, despite the vast amount of research on students' ideas, German chemistry textbooks still contain phrases which might foster common misconceptions. While this study focused on the presence of representations that may enforce alternative ideas, further research is necessary to investigate the presence of text elements that may support students in overcoming misconceptions as well as to investigate the question of how texts can be improved in this respect.

Research on US American science textbooks, in contrast, does already focus on whether and how misconceptions are taken into account. The Project 2061[2] has developed a comprehensive analysis procedure for the evaluation of textbooks which comes up to this aspect. The analysis does not only assess whether the textbook matches the science standards on the content level, but also evaluates whether the instructional design supports students in achieving the standards. One important criterion for the assessment is whether and how the material addresses students' ideas (Roseman et al. 1997). An evaluation of different American science textbooks showed, however, that the textbooks failed to alert teachers to commonly held misconceptions and that they only deficiently provided support how to address the ideas of students (Stern & Roseman 2004).

## 3.2 The theory of text processing

Authors of science textbooks and teachers are challenged to write expository texts which present complex scientific knowledge in a comprehensible way. How should a “prototype comprehensible science text” look like? A main result of several decades of research on text comprehensibility consists in the conclusion that it is impossible to answer this question in general. Comprehensibility has shown to be not only dependent on the design of the text but also on the individual characteristics of the reader, e.g., his or her prior knowledge, learning strategies, interests or intentions. Text comprehension is thus modeled as the product of a text-reader interaction (Artelt et al. 2005).

This entails a practical problem for textbook authors since they have to de-

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[2] The Project 2061 is a long-term project of the American Association for the Advancement of Science to advance literacy in science, mathematics and technology.

velop one text for up to several thousands of students. They cannot take each single reader with his or her individual background into account but only make general assumptions about, e.g., the prior knowledge or the learning strategies of students of a specific age group at a specific type of school. Therefore, although it is not possible to create *the* comprehensible science text, authors should have guidelines for text design which have proven to rise the comprehensibility of a text in general. Even if the result of text processing is strongly dependent on the reader, it is also clear that an appropriate text design provides the basis for effective learning processes (Schnotz 1994, p. 293).

Research has dedicated to the investigation of such text characteristics. Some features have been deduced from the theory of text processing, some have been found by an inductive approach (Schüttler 1994). Before we turn to these specific text characteristics, we look at some basic aspects of a theoretical framework of text processing.

### 3.2.1 Mental representation of a text

When writing a text, an author tries to externalize his or her knowledge about a certain object. This is a difficult endeavor since the internal representation of knowledge is assumed to be very complex, and a network is mostly used as a model for its structure. While concept maps are means to partly externalize such linked knowledge, writing texts demands linearization. Therefor, it is presumed that in order to externalize knowledge about a certain object, an author has to cut down the network into small building blocks. These units are then put into a sequence and expressed with the help of linguistic components. One could expect that a reader of a text re-constructs the same mental representation of the object as the one the author had. This is, however, hardly ever the case since text processing requires the active integration of the information presented in the text into one's own knowledge base. This integration is controlled by the reader's prior knowledge, interests and intentions. Text processing is thus always a combination of bottom-up processes, which are stimulated by the text, and top-down processes, which are stimulated by the reader (Ballstaedt et al. 1981, Schnotz 1994).

The currently used theory of text processing assumes that encoding a text and internalizing its meaning requires different levels of text processing. Further assumptions are that the distinct processes run parallel instead of sequentially and that these processes result in the construction of different types of mental representation (Ballstaedt 1997).

Generally, three types of mental representation are suggested. The surface code corresponds to the lowest level representing the explicit wording and syntax of the text. On the next level, the so called textbase, i.e., a list of propositions[3], is constructed which is close to the information mentioned in the text explicitly. A more elaborated representation of the text is a mental model of the situation described in the text, a so called situation model. Science texts often require another type of mental representation, a so called problem model. The problem model differs from the situation model in that it additionally represents the formal or mathematical relations between the single components which are given in the text (Graesser et al. 2002).

The term "text comprehension" usually refers to the construction of an appropriate situation or problem model (Artelt et al. 2005). The following example elucidates the difference between comprehension on the textbase level and on the situation model level. Rouet & Vidal-Abarca (2002) present a section of a text which describes the evolution of the atomic models. It starts with the statement that Rutherford conducted an experiment which challenged Thomson's atomic model. Following, the experiment is described and the conclusions Rutherford drew are presented. After having read this text one student might simply store that "most of the particles traverse the gold leaf" and relate it to the information that "Rutherford concluded that atoms must be essentially empty" (Rouet & Vidal-Abarca 2002, p. 420). In contrast, another student might elaborate the additional relation that "in a solid body atoms are squeezed together [thus] the particles could not go through the gold leaf except through the atoms themselves" (Rouet & Vidal-Abarca 2002, p. 420). Whereas the first student constructed an appropriate textbase, the situation model is rather poor. The second reader, though, succeeded in grasping the gist of the text by forming a good situation

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[3] Roughly speaking, propositions consist of a predicate and one or more arguments which are interrelated by the predicate, e.g., (comprehensible, text): "The text is comprehensible" or (play(peter, piano)): "Peter plays the piano" (Graesser et al. 2002).

model (Rouet & Vidal-Abarca 2002).

### 3.2.2 Levels of text processing

The different cognitive processes which are assumed to be involved in building the types of representation described above have been studied extensively. Some aspects of this research domain, which are explicated in Ballstaedt (1997), are outlined in the following.

Processes on the lowest level result in the surface code. They are done mostly automatically and deal with recognition of letters and words. Recognizing a word means to activate the knowledge which is represented by the visual sign. On the next level, these fragmented parts of knowledge are interrelated, i.e., the reader extracts and combines propositions. The structure of sentences often signals which propositions should be constructed and how they should be connected. For instance, the sentences "The dog was injured. It has been bitten by the boy." clarify the relation between the propositions (injured, dog) and (bitten(dog, boy)) because of their syntactic structure. Sometimes there is no syntactic connection between two sentences as in the following example: "It was the 10th of January. When John stepped out of the house, he slipped off" (see also Schüttler 1994, p. 34). Here, semantic processing is needed to substitute for the missing syntactic relation. The reader activates his or her prior knowledge in order to add propositions and thus to construct a coherent textbase[4]. Any German child would infer easily that the street was icy and thus made Peter fall. An Australian child, however, would probably have difficulties to understand the meaning. Both syntactic and semantic processing support a reader in constructing a coherent textbase.

To produce a mental model of the text, the reader has to engage in deep inferential processing, i.e., he or she has to engage in elaborative and reductive processing. Elaborative processing is used to link the prior knowledge with the

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[4] A mental representation is called "coherent" when it does not consist of isolated facts but when the individual mental entities are connected to a joined whole. If the coherence of the author's knowledge is reflected in the semantic relations between successive sentences and paragraphs, a text is called cohesive (Schnotz 1994, pp. 16-18).

one extracted from the text. Therefor, the reader produces various associations which connect new and prior knowledge in many ways, e.g., by thinking of examples for general statements in the text. Reductive processing, in contrast, reduces the plethora of information to those which are regarded as most important. To extract these main ideas, the reader neglects unnecessary information, generalizes statements, and searches for more general categories (Ballstaedt 1997).

### 3.2.3 A cyclical model of text processing

Kintsch & van Dijk (1978) developed a model which tries to describe the construction of a mental representation of a text by taking the reader's limited capacity of processing into account. They assume that the construction process of the textbase is based on a sequence of single processing cycles. A cycle can be described roughly by the following sequence. First, the reader transfers a limited number of propositions, a so called chunk, into a working memory. Then, the individual checks for coherence, i.e., he or she tries to combine the propositions into a hierarchical order, a so called coherence graph. A node in a coherence graph represents a proposition extracted from the text and an edge reflects a formal relation between two propositions. To construct such a graph, a main proposition $A$ is chosen as the top of the hierarchy. The next level consists of propositions $B_1, ..., B_n$ which either share an argument with $A$ or which contain $A$ as an argument (argument overlap). In the same way, each node $B_i$ divides into further propositions $C_{i1}, ..., C_{im}$ and so on. At the next step, a part of this graph is selected and transferred into a short-term memory buffer. The whole graph is transferred into the long-term memory. Now, a new chunk is taken into the working memory and the individual tries to create a new coherence graph by combining the new propositions with those stored in the short-term memory buffer (checking for argument overlap). Again, a part of this new graph is chosen, transferred into the short-term memory buffer and the whole graph is again stored in the long-term memory[5] (see Ballstaedt et al. 1981).

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[5] Simultaneously to this organization of micropropositions, Kintsch & van Dijk (1978) assume macrooperators which transform the propositions of the textbase into macroproposition representing the essence of the text.

This model implicates that a text is difficult to process, when related information are presented far away from each other or when the set of propositions lacks argument overlap. In this case, the reader has to engage in extra processing to construct a coherence graph. For example, he or she has to use prior knowledge to draw inferences, has to reinstate a proposition from the long-term memory, or has to restructure existing graphs (Ballstaedt et al. 1981).

The model of Kintsch & van Dijk (1978) has proven of value and it is still the basis on which other models are built. Limitations of this approach are that it is not well applicable to long texts, that the influence of the reader is not well elaborated, and that coherence is tied to formal repetitions (Ballstaedt et al. 1981).

The cyclical model was later extended by Kintsch (1988) to the construction-integration model. This model assumes knowledge to be organized in an associative network which plays an important role for the construction of the textbase. The textbase is not regarded as consisting only of propositions deduced from the text, but also of propositions derived from the reader's knowledge base. It is suggested that in the construction process of the textbase each proposition deduced from the text functions as a key to get associated propositions from the knowledge base, independent of the context. This random elaboration process results in a textbase with a lot of irrelevant information. In order to "trim" the generated textbase and to eliminate incoherence and inconsistency, the model assumes a subsequent integration process. In this process important and consistent aspects of the textbase are strengthened and unimportant and inconsistent are weakened, taking the context into account. The gain of modeling a process with a "dumb and seemingly wasteful process of knowledge activation" at the beginning consists in the power of the model to explain "flexibility and context sensitivity" of text comprehension (Kintsch 1988, p. 180).

## 3.3 Text characteristics

As outlined above, text understanding is regarded as the product of an interaction between text and reader. One and the same text may be easy for some readers, while difficult for others. However, there are some text characteristics which have proven to rise the comprehensibility of a text in general, i.e., for most readers. The investigation of such text features is important for authors in order to have guidelines for writing texts that are comprehensible for a wide range of readers. For defining such text characteristics different approaches have been used. Deductive approaches deduce text characteristics from the theory of text processing and verify their appropriateness in empirical studies. Inductive approaches strive for more heuristic principles. They define text characteristics based on results of empirical studies without the theoretical framework of text processing. In the following, text characteristics defined by inductive and deductive approaches are presented.

### 3.3.1 An inductive approach

Langer et al. (1974, 2002) chose an inductive approach and asked experts to assess the comprehensibility of different texts with regard to different text characteristics. A factor analysis was then conducted which revealed four dimensions that seemed to be crucial for the comprehensibility of a text.

**Simplicity.** Simplicity refers not to the content but to linguistic characteristics like the choice of words or the structure of the sentences. For example, the use of short and simple sentences, the use of common notions, the explanation of technical terms, and a concrete and descriptive representation of contents are linguistic features which rise simplicity.

**Structure.** Structure refers both to the inner and to the outer structure of the text. Inner structure means that the sentences are combined in a logical and comprehensible way, that pieces of information are presented in a meaningful order. The inner structure should be reflected in the outer structure of the text. For example, starting new paragraphs or using headings are features which help visualizing the thread of the text, and highlighting phrases or providing summaries supports the reader in distinguishing important from less important aspects.

**Conciseness.** This criterion calls for a balance between succinctness and necessary redundancy. The text should neither be terse nor prolix. For instance, unnecessary details, many repetitions, fillers or hollow phrases are characteristics which indicate a prolix text.

**Additional stimulation.** Additional stimulations are, for example, direct speech, examples from everyday life, rhetorical questions that prompt thinking, or funny phrases. These additions are intended to motivate the reader and to evoke his or her interest.

An empirical study with more than 900 students was conducted to test whether these four dimensions actually have an influence on the comprehensibility of a text. Each student had to read one out of twelve texts on how to fill in a specific form, and one out of 15 texts on the topic of crime. Although all twelve and 15 texts, respectively, had the same content, they were written by different authors and thus differed in the extent to which they adhered to the four dimensions described above. After having read the text the students were asked to answer questions in written form. The questions tested whether the students had understood the text and what they could remember about it. Results showed that students' performance differed depending on the text they had read. Texts that were understood well differed from those that were understood poorly with regard to the four dimensions (Langer et al. 2002). The hypothesis that the four dimensions have an influence on text comprehensibility was thus confirmed. The single dimensions differed, however, in their strength of influence, with simplicity and structure showing the greatest influence. Langer et al. (2002) concluded that, in essence, a comprehensible text should be characterized by the following characteristics: a high degree of simplicity and structure, and a medium to moderate degree of conciseness. The degree of stimulation may be medium to moderate but only in combination with high structure. Otherwise stimulating additions may rise confusion. Using bipolar characteristics for the four dimensions, the optimal assessment pattern can be represented by the matrix shown in Figure 3.2.

Langer et al. (2002) conducted follow-up studies with science texts which were taken from current textbooks (geography, biology, physics). They wanted to investigate whether a common textbook text might be changed according to the four dimensions so that the revised text would be more comprehensible than

| | |
|---|---|
| Simplicity<br>++<br>(-- complex *to* ++ simple) | Structure<br>++<br>(-- unstructured *to* ++ structured) |
| Conciseness<br>0 or +<br>(-- prolix *to* ++succinct) | Additional Stimulation<br>0 or +<br>(-- not stimulating *to* ++ stimulating) |

Figure 3.2: Optimal combination of the four dimensions according to Langer et al. (2002, p. 33).

the original one. Again several hundreds of students were tested on whether they benefited from the change. Results showed that students who read the new text understood the text better and remembered more important information than readers of the control group. Additionally, an intelligence test was conducted and showed that the degree of benefit from the optimized text was independent of the readers' IQ (Langer et al. 2002).

Based on these results, Langer et al. (2002) developed an instructional program to train authors how to write comprehensible texts. Apolin (2002) underwent this training and rewrote different textbook texts on the special theory of relativity according to the four dimensions. An empirical study was conducted to investigate whether students benefit more from the revised texts than from the traditional textbook texts. Test results showed that students who read the new texts outperformed readers of the traditional texts both on the immediate and on the delayed test. The new texts were additionally assessed as more comprehensible by the students and they liked them better than the traditional ones.

From a theoretical standpoint, the approach of Langer et al. (1974) has been criticized for lacking a theoretical foundation (e.g., Schüttler 1994) since it provides no explanation *why* the four dimensions have an influence, and since it focuses only on text variables. Ballstaedt (1997) points out, however, that other conceptions of text comprehensibility which were embedded in a theoretical frame found basically the same dimensions (see Section 3.3.2).

To sum up, Langer et al. (2002) present an instructional program which helps teachers and textbook authors to write or rewrite expository texts which are, in general, easier to comprehend than texts which do not satisfy the proposed criteria. Deductive approaches have by and large confirmed the criteria of this inductive approach.

### 3.3.2 Deductive approaches

Based on the theory of text processing, deductive approaches also found text variables which generally contribute to the comprehensibility of a text. The plenty of characteristics are summarized in Ballstaedt (1997):

**Features concerning the structure on the content level.** The text design should support the reader in constructing a coherent mental representation. For example, the information should be presented in a logical sequence, important aspects should be emphasized, long passages should be followed by summaries, the text should tie in with the reader's prior knowledge, the macrostructure of the text should be reflected in headings and marginalia.

**Features concerning linguistic aspects.** The linguistic style should not be too challenging. For example, there should be as few uncommon words as possible, technical terms should be explained by well-known words, the sentence structure should be simple, successive sentences should refer to each other and should not require too many inferences.

**Features concerning stimulation and motivation.** The reader should be stimulated to engage in deep and elaborative processing. For example, an appropriate portion of vital expressions or questions can be used to animate and motivate the reader. These elements should foster deeper thinking and rise the reader's interest.

**Features concerning the typographic layout.** The layout should facilitate the processing of the text. For example, fond type and size should be easy to read and the arrangement of the text should visualize its content structure.

With regard to chemistry textbooks in particular, Sumfleth & Schüttler (1995) found linguistic text characteristics which are crucial for the comprehensibility of chemistry texts:

- Realization of the so called “Adressatenbezug”. Scherner (1977) developed this idea following research on thema-rhema (or topic-comment (see Schnotz 1994, pp. 188-189)) to get a concept which is easy to handle and thus applicable at school. “Adressatenbezug” refers to a structure in which each sentence contains at its beginning a part of the information presented in the preceding sentence. This structure results in a logical sequence and supports the construction of a coherent representation of the text.
- Addressing of experiences from everyday life.
- Integration of relevance indicators which direct the reader’s attention to important aspects.

A text in which these features were implemented was developed. The text dealt with the ingredients of detergents and addressed both the macroscopic level of phenomena and the submicroscopic level of models. A study with university students showed that this text was superior to a common textbook text concerning comprehensibility. However, the understanding of the relations between the macroscopic and the model domain was not satisfying in both cases, though still better for the newly developed text (Schüttler 1994).

The “Adressatenbezug” refers to the microstructure of the text. For example, argument overlap or connectives ensure that each sentence is semantically related to its processor. Global cohesion, though, is equally important for the construction of a coherent mental model. Different ideas of a text should be presented successively and continuously, and not disjointed (Gräsel 1990). Headers or topic sentences, for example, should be used for highlighting the macrostructure of a text. They support readers in grasping the logical sequence of the ideas presented in the text as well as the connection of each paragraph to the overall subject (Artelt et al. 2005).

### 3.3.3 Prior knowledge and text cohesion

The preceding sections have shown two important issues. First, learning from text is a highly intricate process. Superficial reading may be sufficient for building a textbase and thus for providing good recall results. Higher-order tasks like problem-solving, in contrast, require the construction of a situation model of the text, a linking between prior knowledge and the information presented in the text (Kintsch & Kintsch 1995). Second, making relations among text ideas more explicit – both on the local and on the global level – supports readers in building a coherent representation of the text. Studies of McNamara & Kintsch (1996), McNamara et al. (1996), and McNamara (2001) suggest, however, that this general rule may not apply to readers with high prior knowledge. In these studies only low-knowledge readers benefited more from highly cohesive texts, particularly with regard to measures assessing deeper understanding. High-knowledge readers learned best from texts which required them to close coherence gaps by making their own inferences. This can be explained with the assumption that readers with high prior knowledge tend to passively process highly cohesive texts. Because of their background knowledge and the putative simplicity of the text, high-knowledge readers may feel like understanding the text without making great effort. Thus, they do not engage in deep processing and therefore do not succeed in constructing an adequate situation model (Kintsch & Kintsch 1995). However, other studies failed to replicate the effect that high prior knowledge readers learn better from low cohesive texts (Gilabert et al. 2005, Kintsch & Kintsch 1995, McKeown et al. 1992). For example, Gilabert et al. (2005) increased the argument overlap of a text on the Russian Revolution but found no interaction between prior knowledge and text design (argument overlap/deficient argument overlap). Further studies investigated explicitly the assumption that high-cohesive texts prevent high-knowledge readers from deep processing. One could assume that the interaction between knowledge and text cohesion would vanish, if all readers were forced to engage in deep processing. To initiate such active reading, Kintsch & Kintsch (1995) asked the participants to comment on their understanding after every sentence while reading a text. Under these circumstances no interaction between cohesion and prior knowledge was found, but both low- and high-knowledge readers benefited from the high-cohesive text. Gilabert et al. (2005) investigated whether a text design that fosters deep processing would show similar results. They changed a text on the Russian Revolution by providing additional information to clarify the meaning of text ideas or causal connections between text events ("causal explanatory"). The added ideas were intended to trigger the reader into making the remaining inferences that were important for understanding the text. Results showed that the causal explanatory text was beneficial for both memory recall and deep comprehension, irrespective of the reader's prior knowledge.

To sum up, the interaction between prior knowledge and text cohesion is not sufficiently investigated yet. The source of the contradictory outcomes of the different studies is difficult to identify since the experiments differed in various aspects (e.g., participants, text topic, text difficulty, knowledge measure, definition of high and low prior knowledge). Overall however, results indicate that both low- and high-knowledge students benefit from high-cohesive texts when they are prompted for active processing.

## 3.4 Conceptual change texts

As discussed in Chapter 2, for learning chemistry it is highly important that teachers know about alternative ideas of students and that addressing of these ideas is regarded as an integral part of teaching. Similarly, authors of textbooks should try to design texts in which common misconceptions are taken into account. In the following sections we look at the special genre of conceptual change texts which comes up to this demand.

### 3.4.1 Structure of conceptual change texts

“Conceptual change texts” are also referred to as ”refutational texts” since they usually try to produce a cognitive conflict by refuting an alternative idea. They generally adhere to the following pattern (Chambliss 2002):

1. Presentation of the naive ideas based on everyday experiences
2. Demonstration of the limitations of the naive ideas
3. Presentation of the scientific concept
4. Highlighting how the scientific concept addresses the limitations

Conceptual change texts thus roughly follow the instructional strategy proposed by Posner et al. (1982). In this context, we already discussed that students are often not aware of inconsistencies or anomalies which are presented in order to evoke a cognitive conflict. These difficulties are also observed with regard to conceptual change texts. In order to decrease these problems, it is important that the text explicitly states which idea is currently accepted by the scientific community and which is not, and that the teacher also takes time to discuss the ideas presented in the text with the students (Guzzetti et al. 1997).

There are different ways how to design conceptual change texts concretely. In the following, different studies are presented that were concerned with using texts for fostering conceptual change.

### 3.4.2 Effectiveness of conceptual change texts

Alvermann & Hague (1989) conducted a study on the topic of Newtonian mechanics using a 2 x 3 factorial design. The first factor, text design, comprised the levels of conceptual change text and of non-conceptual change text. Whereas the non-conceptual change text only referred to Newtonian mechanics, the conceptual change text also addressed and refuted the impetus theory explicitly. The second factor, comprising three levels, referred to the mode of activation before reading the text. Students on the first level had to illustrate and explain the path of a marble when shot from a table and they were then given a short text passage presenting common misconceptions about this topic. The passage additionally warned the students explicitly that, if they agreed to one of these ideas, a few of the ideas presented in the following text would probably not match their own. Students on the second level only performed the illustration/explanation activity, and third level students did neither of the activities. In the second phase of the experiment the subjects either read the conceptual change or the non-conceptual change text. Results showed that students benefited from the conceptual change text, and that it is important to explicitly alert students to possible differences between their own ideas and the scientific ideas presented in a text.

Wang & Andre (1991) developed a similar text on electric circuits which also proved to be more effective than common non-conceptual change textbook texts. Here, the readers were first presented with a circuit diagram and asked whether the circuit would work and why they think so. Then, common misconceptions and the corresponding counter evidences were presented. However, students who did a pre-test and read the traditional text performed just as good as those who read the conceptual change text. This observation is explained in that the conceptual items of the pre-test may have sensitized the participants to alternative ideas in a similar way as the conceptual change text did.

Mikkilä-Erdmann (2001) conducted an empirical study with ten to eleven year old students focusing on the aspect of metaconceptual awareness. The study compared the effectiveness of a traditional textbook text on photosynthesis with that of a conceptual change text. The conceptual change text was characterized by elements highlighting the difference between the commonly held misconception of "water is food for a plant" and the concept of photosynthesis (e.g., "It is important to understand that a plant does no take ready-made food through its roots from the soil. So a plant does not eat but makes its food in the chloroplasts ..." (Mikkilä-Erdmann 2001, p. 246)). These elements intended to foster students' metaconceptual awareness ran through the whole text. Additionally, the conceptual change text tried to evoke a cognitive conflict right at the beginning by mentioning the crucial difference in the production of energy: "Plants and animals need energy to live and this comes from food. How plants get their food happens in a different way than we normally think. How does the energy get into a plant? Is water food for a plant? ... Plants differ from all other organisms because they make their food by themselves" (Mikkilä-Erdmann 2001, p. 255). In the following, however, the text only explained the concept of photosynthesis and did not provide counter evidence why the idea of "water = food" is insufficient, i.e., no data was presented such as the absence of starch in leaves that have not been exposed to light for some days. Yet, the test results of the study showed that this text, which continuously made students aware of the differences between the alternative idea and the scientific concept, supported the development of conceptual understanding better than the common non-conceptual change textbook text.

Besides these encouraging results, a study of Diakidoy et al. (2002, p. 18) on the concept of energy showed "that the positive influence of the refutation text was more evident in the overcoming of the particular preconceptions that it addressed than in the acquisition of the concepts targeted by standard instruction." This is not surprising since conceptual change is a gradual, long-term process. Reading a single text will hardly enable students to deeply understand complex concepts. Yet, this conclusion is not crucial as textbooks are only one of several teaching materials which have to be orchestrated by teachers into a multifaceted learning environment. Even distance study programs, which are mainly based on texts, provide students usually with more than one text on a certain topic and they provide additional help like discussion forums and exercises.

In general, conceptual change texts, i.e., texts that address common misconceptions by refuting them and contrasting them with the scientific view, proved to be better in bringing about conceptual change than texts which simply present the scientific concept without addressing students' ideas as a meta-analysis of Guzzetti et al. (1993) showed. Thus, conceptual change texts seem to be an important medium to support instruction which aims at fostering conceptual change.

### 3.4.3 Application of conceptual change texts

During the last years, there have been some studies on how to integrate conceptual change texts effectively into the classroom. The investigation of this question is important since conceptual change texts could serve as an easy to handle medium between conceptual change research and teaching practice. On the one hand, conceptual change texts offer the chance to inform teachers domain-specifically about common misconceptions. On the other hand, conceptual change texts can be used by teachers as concrete teaching materials, and they provide at least one didactic suggestion how to deal with alternative ideas.

Çakir et al. (2001), Çakir et al. (2002) and Yuruk & Geban (2001) developed conceptual change texts on cellular respiration, on acids and bases and on electrochemical cells, respectively. The authors conducted empirical studies in which science teachers integrated the conceptual change texts into their instruction. For example, students were first asked to read the conceptual change texts at home. Then, in the next lesson, there was a discussion about the text. A further study investigated the combined application of concept mapping and conceptual change texts (Tekkaya 2003). The results of all studies showed that students who received a conceptual change text instruction outperformed students of the control group who were taught traditionally (no concept maps, traditional textbooks). It is not clear, though, whether the positive effects are only due to the conceptual change texts or also to other factors (e.g., discussions about misconceptions, concept mapping).

The overall positive results of the integration of conceptual change texts into the classroom are supported by the fact that this type of text is highly appreciated by students as the following comments show (Hynd & Guzzetti 1998, pp. 153-154):

- ”What most people think is wrong is what you think, too.”
- ”It was like it was talking to me.”
- ”It makes me feel like I’m not the only one.”
- ”It makes you think twice about what you think you know.”

These statements indicate that conceptual change texts address affective variables and may thus motivate students more than traditional texts. This effect may be one reason for the increase in learning. Another argument for the use of conceptual change texts consists in the observation that both male and female students seem to benefit from these texts (Chambers & Andre 1997).

## 3.5 Conclusions

There are many open questions concerning the application of texts in the chemistry classroom and concerning the quality of current chemistry textbooks in Germany. There is hardly any recent research on the use or quality of chemistry textbook texts available. Research results from German physics education suggest that it is not the students but the teachers who are the main beneficiaries of science textbooks. Teachers use textbooks for their lesson planning, but they seldom seem to integrate texts explicitly into the classroom. Revision and consolidation appear to be the dominant fields for the use of textbooks. The study presented in Chapter 5 investigated whether this picture is also prevalent in chemistry teaching.

Texts might be used more in science classes if they were more comprehensible for the students. Although the comprehensibility of a text is essentially dependent on the characteristics of the reader, there are some text inherent characteristics which rise the comprehensibility in general, i.e., for most readers. The few studies which investigated this aspect for German science textbooks indicate, however, that the texts do not adhere to these guidelines sufficiently.

In order to support students in constructing conceptual knowledge from reading a text it is not only important to adhere to principles of text comprehensibility but also to take students' alternative ideas into account. As discussed in Chapter 2, it is widely agreed that students do not enter science or other classes as blank slates, but that they bring along their individual ideas about various topics. These ideas are assumed to form the basis on which further learning occurs. However, students' ideas often contradict the scientific view and might impede learning if not addressed appropriately. Working with students' prior knowledge is therefore regarded as one the of key principles of teaching (Bransford et al. 2000*d*). Conceptual change texts try to meet this basic criterion by not only presenting the scientific perspective but also common alternative ideas. Research has shown that such texts which address and refute common misconceptions and contrast them with the scientific view support students better in building conceptual understanding than texts which do not address common misconceptions. Whether and how German chemistry textbook texts take alternative ideas into account is investigated in Chapter 6.

Overall, it can be assumed that textbook texts which adhere to principles of text comprehensibility and which also address common ideas of students can function as highly supportive media for instruction that focuses on learning with understanding. A suggestion of how to improve chemistry texts with regard to these crucial aspects is presented in Chapter 7.

# 4

# Models in chemistry education

One important goal of this thesis is to present a suggestion of how to improve chemistry texts with regard to the aspects of text comprehensibility and students' ideas. In this context, design criteria are presented in Chapter 7 which are implemented in an expository text. The topic of the text is the introduction of the particle model. Basic aspects of models in chemistry education are therefore outlined in this chapter.

The first part of the chapter deals with models in chemistry classes in general. The notion of scientific model (Section 4.1.1) and common ideas of students about the nature of models (Section 4.1.2) are discussed, as well as some implications for instruction (Section 4.1.3). In the second part of the chapter a simple particle model is presented as it is often used in introductory chemistry courses (Section 4.2.1). Common ideas of students about this simple particle model (Section 4.2.2) and some implications for instruction are discussed at the end (Section 4.2.3).

## 4.1 Models in science education

### 4.1.1 The notion of model

The notion of model is used in different areas such as art, fashion or mathematics with different meanings. In science, a model ”expresses an interpretation of an empirical phenomenon which facilitates the (intellectual) access to this phenomenon. Interpretations are based on idealizations, simplifications and analogies.” (“Ein

Modell drückt eine Interpretation eines empirischen Phänomens aus, und zwar auf eine Weise, die den (intellektuellen) Zugang zu diesem Phänomen erleichtert. Interpretationen kommen zustande z.B. durch Idealisierung, Vereinfachung oder Analogisieren.") (Bailer-Jones 2000, pp. 1-2). Another approach to characterize models is to compile features that all scientific models share (van Driel & Verloop 1999, pp. 1142-1143):

1. *"A model is always related to a target, which is represented by the model."*
2. *"A model is a research tool which is used to obtain information about a target which cannot be observed or measured directly ..."*
3. *"A model cannot interact directly with the target it represents."*
4. *"A model bears certain analogies to the target ... "*
5. *"A model always differs in certain respects from the target."*
6. *"In designing a model, a compromise must be found between the analogies and the differences with the target ..."*
7. *"A model is developed through an iterative process ... "*

These features qualify models to have a descriptive, explanatory, and predictive function (van Driel & Verloop 1999). They can be regarded as an "intermediary between the abstractions of theory and the concrete actions of experiment" (Gilbert & Boulter 1998, p. 54). In chemistry, most of the models refer to the submicroscopic level. For example, structural models provide descriptions of the constitution of substances, they explain characteristics of the substances, and models of protein structures are used to make hypotheses about the structure of potential active substances.

The notion of scientific model as it is used here does not refer to scale models (van Driel & Verloop 1999). In this context Becker et al. (1992, p. 409) suggest to use the notions of "Sachmodelle" (concrete models) and "Denkmodelle" (mind models) in order to distinguish scale models, e.g., models of cars, from "speculative and theoretical interpretations of reality" ("spekulative und theoretische

Interpretationen der Realität"), e.g., models of atoms. An example for a scientific model that all students encounter early in their science education is presented in Section 4.2.1.

How are scientific models developed? One can assume that an individual first constructs a mental representation of a specific object, system, phenomenon or process, i.e., a mental model is built. When the individual wants to communicate his or her mental model to others, he or she has to express it with the help of gestures, pictures, spoken or written language. If such an "expressed model" is generally accepted by the scientific community, it changes its status to a "scientific model" (Justi & Gilbert 2000, p. 994). However, when empirical data arise which can not be explained with the respective scientific model, the model may be revised. The appropriateness of the revised model is tested by further investigation of the target (van Driel & Verloop 1999).

### 4.1.2 Students' ideas about the nature of models

An important aspect of science education is that students develop a disposition for asking questions about everyday phenomena and that they try to find explanations for these phenomena using the scientific theories and models they have learned. The ability to use models appropriately is not only important for succeeding in science classes but also for participating successfully in social life, e.g., for analyzing climate calculations or economy prognoses. Developing modeling skills is seen as a central aspect of becoming scientifically literate (Prenzel et al. 2001). Therefore, most chemistry curricula require students not only to become familiar with different models but also to develop an understanding of the nature of models (Kultusministerkonferenz 2005*a*, NRC 1996).

Doing chemistry is stamped by a permanent back and forth between making observations on the macroscopic level and explaining these observations on the submicroscopic level using models. While experts, like teachers, are able to easily and often unconsciously jump between the different levels, novices, like students, sometimes have difficulties in following these mental steps (De Jong & Van Driel 1999). The students are challenged to think on a highly abstract level when working with models. In order to facilitate these thinking processes students are often presented with visualization models such as pictures of Rutherford's atom model or small balls for visualizing a particle model. When such "models of models" (Becker et al. 1992, p. 410) are used in the classroom, one has to pay attention that students' do not equate visualizations of mind models with concrete models such as car models.

Research has overall shown that the development of understanding of the nature of models and their role in science is a challenging process which takes time. For example, students think of models rather as provable facts than as hypothetical constructs (Fischler & Peuckert 1999). The notion of model is rather associated with concrete objects (e.g., replicas of airplanes) than with representations of ideas. Aspects of knowledge gain such as generating new hypothesis or testing competing theses using different models are seldom associated with the notion of model. Models are rather seen as tools of communication which are used to support teaching and learning (Grosslight et al. 1991).

### 4.1.3 Implications for instruction

As any other teaching, instruction for model understanding has to tie in with students' prior knowledge and their individual ideas. Clement (2000) interprets the pathway of students' learning as a series of intermediate models towards a defined target model. The learning processes are based on students' preconceptions and reasoning skills (see Figure 4.1).

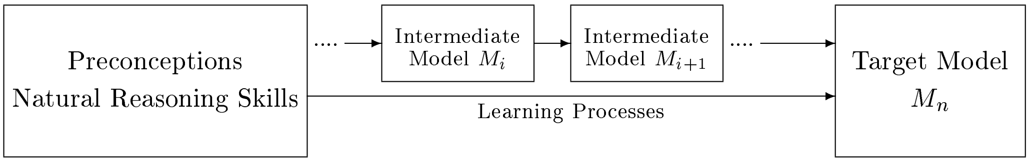

Figure 4.1: A framework for model construction in the classroom (Clement 2000, p. 1042).

The framework defines a target model $M_n$, i.e., a model the students are supposed to master after instruction. This model does not necessarily need to be the scientific model that is currently used in the scientific community, but may be a simplified model depending on students' age and ability. The starting point in this framework is a map of students' initial ideas including both ideas which might conflict with the target model and ideas which might serve as building blocks towards it. The way from students' preconceptions to the target model is thought to lead via one or more intermediate models. The framework is not thought of as a tool for the class as a whole but for "thinking about cognitive content learning events in individuals" (Clement 2000, p. 1043). From an instructional point of view, teachers have to first elucidate students' preconceptions. Then, they have to adapt their instruction accordingly, i.e., they have to plan activities which support each student in moving from his or her initial ideas to an intermediate model, or from an intermediate model $M_i$ to a more sophisticated model $M_{i+1}$ (Clement 2000).

The idea of intermediate models which are based on and constrained by students' prior knowledge is similar to Vosniadou's (1994) assumption of synthetic (mental) models. These intermediate models can be seen as necessary steps to bridge the gap between students' initial ideas and the scientific view. Instruction that follows this framework needs to give students room to express their models. Students will see that their model might differ from the models of their peers. Criteria for evaluating the quality of a model need to be discussed. In other words, metadiscussions about models have to be an essential part of instruction. Such discussions are regarded as important for the development of model understanding as the intense and frequent use of models in the classroom (Grosslight et al. 1991). Students should be encouraged to use multiple models for explaining a phenomenon and they should discuss the strengths and limitations of the different models (Coll & France 2005, Harrison & Treagust 2000).

A comprehensive teaching approach for physics education which focuses on metaconceptual discussions about models has been developed and tested by Mikelskis-Seifert & Fischler (2003*b*) and Mikelskis-Seifert & Fischler (2003*a*), respectively. The subject was the introduction of a simple particle model and the intention was to foster students' metaconceptual awareness. In this context, the notion of metaconceptual awareness is used in a similar way as the notion of metaconceptual understanding is used in this thesis (Mikelskis-Seifert & Fischler 2003*b*, p. 81):

1. The students have knowledge about physical concepts, about their character, and about everyday concepts.
2. The students can use and adjust this knowledge, e.g., for identifying existing relations or for applying their knowledge to other domains.

The overall structure of the suggested teaching unit included four phases (Mikelskis-Seifert & Fischler 2003*b*). In the introduction phase the students are encouraged to express their ideas about the submicroscopic world, and the different perspectives of the world of experiences (or perception) and of the world of models are introduced. A first particle model is developed. During the phase of elaboration, the students describe and explain a phenomenon such as the change of volume of a heated liquid with the help of the particle model using different levels of representation. The application phase asks the students to apply their knowledge to other phenomena such as evaporation. The unit ends with a reflection on the modeling processes. Here the students also discuss "pictures" of submicroscopic entities (e.g., scanning tunneling microscopy). The whole teaching unit is stamped by metaconceptual discussions about models. In order to develop metaconceptual awareness, the students should deeply engage in exploring the characteristics of and differences between the world of experiences and the world of models (see Figure 4.2). They should learn to take different perspectives by using multiple representations. Therefor, a system with different levels of representation was developed (see Figure 4.3). This level system can be used by teachers for planning and analyzing their instruction (e.g., "On which levels of representation do the students work in this particular lesson?"). On the other hand, the system can be used during instruction as a supportive tool for metaconceptual reflections (Mikelskis-Seifert & Fischler 2003*b*).

The effectiveness of the instructional approach was tested in an empirical study with 120 ninth and tenth graders (Mikelskis-Seifert & Fischler 2003*a*). Results showed that the students developed an overall appropriate and stable understanding of the particle model. The degree of students' learning process differed among the classes, though. The digital audio recordings of two classrooms which differed in the degree of students' learning were exemplarily analyzed. The analysis revealed differences in the quantity of metastatements made by the

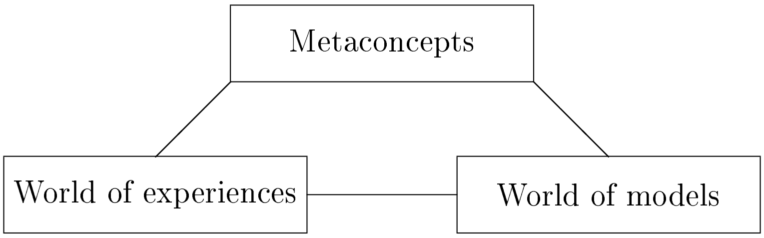

Figure 4.2: Metaconceptual awareness about the world of experiences and the world of models (Mikelskis-Seifert & Fischler 2003*b*, p. 81).

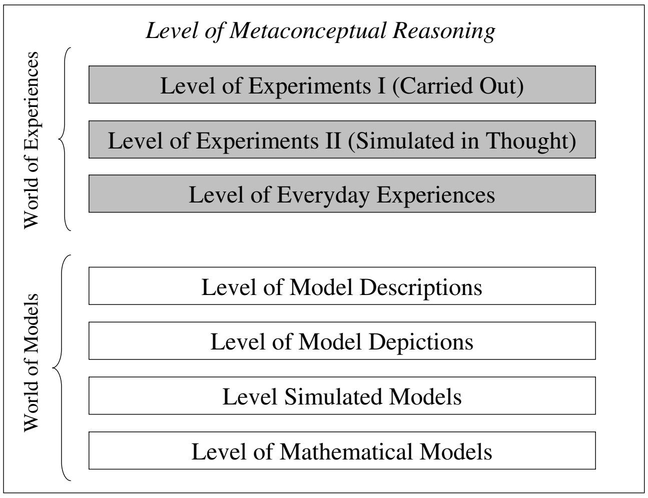

Figure 4.3: The level system of multiple representations (Seifert & Fischler 1999, p. 3).

teachers. Thus, metaconceptual discussions about models seem to play a pivotal role for the construction of elaborated model understanding (Mikelskis-Seifert & Fischler 2003*a*).

## 4.2 Models of the particulate nature of matter

While the preceding part of the chapter focused on models in science in general, the following part is concerned with a simple model of the structure of matter in particular. The model is presented in more detail since it was chosen as the topic of the text developed in Chapter 7.

The hypothesis of a discontinuous structure of matter is regarded as one of the most important ideas in science, and it is part of all chemistry and physics curricula. During their chemistry education, students follow the path from simple to more sophisticated models of submicroscopic entities. The first model they encounter is a simple particle model which does not distinguish between atoms, molecules or ions.

### 4.2.1 A simple particle model

The introduction of a particle model in the introductory chemistry course is a milestone, since students are introduced into the modeling of the submicroscopic world. Additionally, they are familiarized with one of the main aspects of chemistry, i.e., the interpretation of macroscopic phenomena on a submicroscopic level. A particle model as it is often introduced at the beginning of chemistry education can be characterized by the following assumptions (e.g, Asselborn et al. 2001, Eisner et al. 2001):

- Substances consist of smallest particles[1].
- The particles of a pure substance are alike. The particles of different substances differ from each other in their size and mass.
- The particles move constantly.
- The higher the temperature of the substance, the faster the particles move.
- There is nothing between the particles.
- There are forces of attraction between the particles.

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[1] Although most textbooks introduce this statement as an assumption of the particle model, it may be questioned whether it should rather be introduced as the hypothesis of the discrete structure of matter with the particle model as one possibility of how to model the assumed building blocks of matter.

This model is rather simple, but nevertheless a powerful tool in chemistry. For example, students can use this model for a first explanation of chemical change, conversation of matter, phase change, dissolving or diffusion.

### 4.2.2 Students' ideas about the particle model

Misconceptions about the particle model have been investigated intensively and reported frequently (e.g., Barke & Harsch 2001*b*, Duit 1995*a*, Fischler & Lichtfeldt 1997, Parchmann & Schmidt 2003). Despite the development of experiments, visualization models, computer simulations, and whole teaching units intended to support learning in this context, studies repeatedly find that students struggle with building appropriate model understanding. It seems also difficult for students to apply the particle model consistently across different substances (Nakhleh et al. 2005, Parchmann & Schmidt 2003).

The most common misconceptions about the particle model can be summarized under the following headings: *Nature of the particles*, *Environment of the particles*, and *Model thinking* (see also Fischler & Lichtfeldt (1997, p. 5) and Mikelskis-Seifert (2002, p. 17)).

**Nature of the particles.** Macroscopic behavior and features are transferred to the particles. Common ideas are that the particles have a color, melt when heated, are motionless, or stop moving after a while.

**Environment of the particles.** It is assumed that the space between the particles is filled with a continuous substance. Common ideas are that air fills the space between the particles or that water particles are embedded into water.

**Model thinking.** A naive-realistic view is taken. Common ideas are that there is a right model, that models are copies of reality or provable facts.

While appropriate ideas about the nature of models in general are an important part of understanding the nature of science, appropriate ideas about the particle model in particular seem to correlate with understanding chemical change. Results of a three year longitudinal study (11 year old students up to 14) suggest a relationship between the view of properties as *collective* properties of particles and an appropriate understanding of chemical change (Johnson 1999). Transfer of macroscopic features to submicroscopic particles seems thus to be a misconception which may negatively influence the further learning process in chemistry classes.

In addition to the most common misconceptions listed above, the use of formulations which indicate a transfer of human features to submicroscopic entities has also been regarded as problematic (e.g., "positive ions like negative ones"). However, a recent movement in biology education argues against the taboo of anthropomorphic formulations in the classroom (Kattmann 2005, Zohar & Ginossar 1998). Arguments given for a new perspective on this aspect are that the use of anthropomorphic formulations does not necessarily reflect misunderstanding, but that students might use these expressions consciously in a metaphoric sense (as a lot of scientists do). It is argued that it has still to be investigated whether the complete avoidance of anthropomorphic formulations actually leads to a better scientific understanding compared to an instruction that uses anthropomorphic formulations in combination with discussions about their metaphorical character. Such metadiscussions are seen as particularly important since, even if teachers try to avoid anthropomorphic formulations, students are still confronted with them in the media (Zohar & Ginossar 1998). There are also indications that the use of anthropomorphic formulations enhances students' interest for the scientific content. With regard to chemistry education, a study of Püttschneider & Lück (2004) found that the use of animistic ideas[2] improved students' motivation, and that students were aware of their metaphorical character. These results encourage further research in this area.

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[2] The notion of animism is used in a more general sense than the notion of anthropomorphism and refers to "assigning a spirit to inanimate nature by using analogies and metaphors" ("Beseelung der unbelebten Natur mittels Analogie- und Methapherbildung") (Püttschneider & Lück 2004, p. 167).

### 4.2.3 Implications for instruction

When teachers introduce a simple particle model, they have to make some crucial decisions. When they choose a deductive approach, instruction might be too abstract or demotivating for students. When an inductive approach is chosen, students might think that a model can be deduced unambiguously from experimental data (see Mikelskis-Seifert 2002). Being aware of these aspects, teachers can adjust their teaching accordingly, e.g., by planning metadiscussions about the relationship between theory and evidence.

Another question concerns the use of visualizations. In order to support students in understanding the abstract idea of smallest building blocks, visualizations such as colored balls or pictures with spheres are used. In this context, one has to be aware of the pitfall that students might interpret the balls as simplified representations of reality and not as visualizations of a hypothesis (Fischler & Peuckert 1997). Although there are claims against the use of such visualizations for the particle model (Buck 1994*a*), the discourse has overall agreed on the trade-off of using visualizations accompanied by metadiscussions about models and about the problems inherent to visualizations (Fischler & Lichtfeldt 1997). These discussions have become indispensable since the media regularly presents pictures of electrons, atoms, or molecules. Students bring these impressions into science classes and often believe that new technologies such as scanning tunneling microscopy provide pictures of how submicroscopic entities “truly” look like. These pictures offer an opportunity to discuss the theory dependency of the interpretation of the outcome of scientific apparatuses (Mikelskis-Seifert 2002).

Further specific suggestions for instruction are discussed in Section 7.2.2.

## 4.3 Conclusions

The development of model thinking is an intricate process, and students need to be given room and time for exploring and shaping their ideas. There is no silver bullet for instruction, but metadiscussions about the nature of models and their visualizations seem to be crucial for effective teaching. It is, therefore, important to develop specific anchors that help teachers to integrate metadiscussions regularly into the classroom. A wall-chart with the level system suggested by Mikelskis-Seifert & Fischler (2003*b*), provocative statements or questions, or a text as it is presented in Chapter 7 may be tools for engaging students in such discussions about modeling.

Students are usually introduced into scientific modeling right at the beginning of their science education by learning about the particle model[3], a simple model of the structure of matter. Understanding the particle model seems important for comprehending key concepts of chemistry such as chemical change, for developing model thinking, and thus also for developing understanding of the nature of science. However, research in chemistry and physics education has repeatedly found that it is difficult for students to understand the particle model, despite the great effort that has been put into designing specific instructional approaches. While a lot of research has focused on cognitive variables, it might be promising in this context to take affective variables more into account. For example, are students of this specific age group (usually seventh or eighth grade) interested in model thinking? How do they cope with the aspect of uncertainty? Would they like science to provide “definite and true” answers?

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[3] Simplifying, the definitive article is used here in connection with the notion of particle model in order to refer to the most common model that is introduced in German chemistry classes (see Section 4.2.1).

# 5

# Study 1 – Texts in chemistry classes: Survey of chemistry teachers

For developing quality textual material for teaching practice it is important to know how texts are actually used in the classroom and what aspects of current textbook texts need to be revised from a practitioner's point of view. A survey of 240 chemistry teachers was conducted in order to investigate how texts are used in the chemistry classroom, how satisfied chemistry teachers are with current textbook texts, whether there are differences among the teachers concerning this aspect, and what teachers suggest for the improvement of textbook texts[1].

## 5.1 Theoretical background

Theoretical perspectives and empirical research on text comprehensibility have been discussed in detail in Chapter 3. In the following, only a selection of aspects is outlined in order to provide a short framework for the study presented in this chapter.

Modern societies heavily rely on written information in order to transfer and disseminate knowledge. This tendency is even reinforced by the rise of the Internet. Against this background, reading literacy is regarded as key to successful participation in social life. A main task of school education is therefore to enhance students' literacy and to prepare them to become lifelong learners (Artelt

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[1] Main results of the study presented in this chapter have been published in Beerenwinkel & Gräsel (2005).

et al. 2001, Kirsch et al. 2002). Each student should be able to read, understand, critically assess, and learn from texts. Teachers of all subjects have to engage in this challenging task (Baumert et al. 2001, Lange 2004, Schaffner et al. 2004). Research on text comprehensibility shows that meaningful reading is a highly intricate process. The construction of adequate situation and problem models requires deep processing and the application of sophisticated cognitive strategies (e.g., Artelt et al. 2001, Artelt et al. 2005, Graesser et al. 2002). For enhancing students' literacy it is not only necessary to focus on the development of cognitive skills, but also on motivational aspects, i.e., on students gaining a positive attitude towards reading and learning from texts (Artelt et al. 2001). Concerning the notion of text, it has to be mentioned that there is no general definition. In the following, we confine ourselves to continuous expository texts. In contrast to discontinuous texts such as tables or graphs, continuous texts are made up of sentences which are arranged into paragraphs (Artelt et al. 2001).

Since science texts differ from other texts not only in content, but also in structure and language (Fang 2005), experts, like science teachers, are needed for guiding students with texts of this specialized genre. At a first glance, integrating texts into the classroom seems to contradict basic guidelines of motivating chemistry instruction, which emphasize the use of experiments and student-oriented teaching methods. However, the use of texts in chemistry classes does not question the pivotal role of these components. Texts can never substitute experiments and they should definitely not be used to present students with results they could have found out by themselves. Texts are rather regarded as an integral part of student-centered instruction. Conducting an Internet research, learning from examples, reading experiment procedures, working with computer programs, or working at learning stations – all these activities require the ability to cope with science texts competently. Additionally, texts may serve different functions. For example, at learning stations texts can provide background information, they can show connections to everyday experiences, present complex problems, or encourage students to reflect deeply on specific issues. Textbooks and other texts can therefore contribute to individualize and differentiate learning (Merzyn 1994). The challenge for teachers is to decide which texts should be used and how they can be integrated and connected with other instructional components (e.g., experiments). Efler (2005*b*, 2005*a*) developed a teaching unit on water which was based on a well-directed, selective use of texts and which was tested with eighth graders. Results indicate that a well-directed use of texts may contribute to the quality of chemistry classes. Students seemed to conduct and interpret experiments more independently, and particularly quiet students seemed to benefit from the use of texts.

### 5.1.1 The use of textbooks in chemistry classes

Although it is highly important that students develop adequate reading literacy with regard to science texts, there is little knowledge about the role of language in German science classes (Starauschek 2004). Regarding the use and comprehensibility of texts, there are some studies within physics education, which showed that textbooks are mainly used for revision and consolidation, mostly in homework (Bleichroth et al. 1987, Merzyn 1994, Schäfer 1983, Starauschek 2003), and that students are hardly taught how to deal with science texts (Merzyn 1994). We can assume that the use of texts in chemistry instruction shows a similar pattern. As discussed above, a negligence of texts in science classes would be problematic for several reasons. On the one hand, texts are an integral part of challenging and student-oriented learning environments. On the other hand, only experts like science teachers can support students in becoming scientifically literate. Research on conceptual change instruction provides another reason for integrating texts regularly into the science classroom. Texts which address and refute common alternative ideas of students have proven to support students in overcoming misconceptions (e.g., Guzzetti et al. 1993, Mikkilä-Erdmann 2001). They may thus be used as an effective learning aid in this context[2].

### 5.1.2 Comprehensibility of textbook texts

Producing individual texts, particularly with regard to the variety of topics, grade levels and students, is a highly time consuming process for teachers. Textbooks are thus an important source for teachers since they include texts on all relevant

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[2] More detailed information about conceptual change texts can be found in Section 3.4.

topics. Additionally, the use of textbook texts saves teachers from making hundreds of photocopies since, in most of the cases, students have a textbook at their disposal. The question of how teacher use texts is therefore closely related to the question of how satisfied they are with the textbook which is used at their school.

One of the most important features of expository texts is comprehensibility for the according target group, in this case for students. It is widely agreed that text comprehension does not only depend on the text itself, but also on the readers' attitudes, prior knowledge and interests. The aspect of reader-text interaction thus forms the basis of elaborated theories on text comprehensibility (Artelt et al. 2005). However, teachers and textbook authors cannot produce individual texts meeting the special needs of each student. Instead, they are challenged to design texts that are interesting, motivating and comprehensible for a wide range of students. Thus, teachers and textbook authors have to rely on text features which enhance the comprehensibility in general, i.e., for most readers. In this context, Langer et al. (1974, 2002) investigated which factors are responsible for the comprehensibility of expository texts. The following four dimensions were found:

**Simplicity.** Simplicity refers not to the content but to linguistic characteristics like the choice of words or the structure of the sentences. For example, the use of short and simple sentences, the use of common notions, the explanation of technical terms, and a concrete and descriptive representation of contents are linguistic features which rise simplicity.

**Structure.** Structure refers both to the inner and to the outer structure of the text. Inner structure means that the sentences are combined in a logical and comprehensible way, that pieces of information are presented in a meaningful order. The inner structure should be reflected in the outer structure of the text. For example, starting new paragraphs or using headings are features which help visualizing the thread of the text, and highlighting phrases or providing summaries supports the reader in distinguishing important from less important aspects.

**Conciseness.** This criterion calls for a balance between succinctness and necessary redundancy. The text should neither be terse nor prolix. For instance, unnecessary details, many repetitions, fillers or hollow phrases are characteristics which indicate a prolix text.

**Additional stimulation.** Additional stimulations are, for example, direct speech, examples from everyday life, rhetorical questions that prompt thinking, or funny phrases. These additions are intended to motivate the reader and to evoke his or her interest.

Studies of Langer et al. (2002) showed that comprehensible texts require the following combination of features: a high degree of simplicity and structure and a medium degree of information density. Additional stimulations enhance the comprehensibility only in combination with high structure and simplicity. Apolin (2002) rewrote texts from physics textbooks according to these criteria and showed that the modified texts were more comprehensible for students and that they liked them better than the original textbook texts.

With regard to German chemistry instruction we hardly found any studies on this problem. One of the few studies was conducted by Schüttler and Sumfleth (1994, 1995) who analyzed a textbook text on detergents. The analysis revealed severe shortcomings concerning criteria of text comprehensibility. Although the text used short sentences and common words, “the contents were presented in an either too complex, ambiguous or incongruent way” (“die Sachverhalte entweder zu komplex, uneindeutig oder inkongruent dargestellt werden”) (Schüttler 1994, p. 84). Studies on physics also demonstrated that students have difficulties to read and learn from textbook texts (Apolin 2002, Bleichroth et al. 1987). Overall, there seems to be an urgent need for improving the design of current science textbook texts.

To find linguistic text features which are relevant for the comprehensibility of chemistry texts Schüttler and Sumfleth conducted further studies on text design. Results showed that it is important to adhere to the so-called Adressatenbezug, a concept developed by Scherner (1977) who followed research on thema-rhema (or topic-comment (see Schnotz 1994, pp. 188-189)). ”Adressatenbezug” refers to a structure in which each sentence contains at its beginning a part of the information presented in the preceding sentence. This structure results in a logical sequence and supports the construction of a coherent representation of the text. The integration of relevance indicators pointing out main aspects as well as the addressing of everyday experiences are additional features which enhance the comprehensibility of chemistry texts (Sumfleth & Schüttler 1995)[3].

The importance of addressing everyday experiences or students' ideas in general is regarded as key to learning science (e.g., Driver et al. 1985*a*, Duit 1999, Sumfleth 1992) and has been discussed in detail in Chapter 2. The notion of students' ideas does not only refer to everyday ideas but also to misconceptions developed under instruction. A non-addressing of these ideas might result in learning difficulties (Treagust et al. 2000). It is therefore crucial that textbook texts take common misconceptions into account and focus on building connections between the alternative ideas of students and the scientific perspective. However, guidelines for teachers for assessing and selecting chemistry textbooks, found in German literature, mostly neglect this aspect (Barke & Harsch 2001*c*, Becker & Pastille 1988, Bleichroth 1987).

To sum up, there is hardly any research on the use of texts in chemistry classes, although both the development of reading literacy and the use of student-oriented teaching methods require teachers to integrate texts into their teaching. Against this background, we conducted a survey of chemistry teachers to determine how teachers actually use texts in their teaching as well as how satisfied they are with current textbook texts.

## 5.2 Research questions

The following research questions were investigated:

1. How do chemistry teachers use texts in their teaching?

2. How do teachers assess current textbook texts and what are their expectations?

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[3] More detailed information about research on features rising the comprehensibility of a text can be found in Section 3.3.

3. Are there groups of teachers that differ in how they use texts in their teaching? What are characteristics of these groups?

## 5.3 Method

### 5.3.1 Design and procedure

A postal questionnaire survey of Gymnasium chemistry teachers from four German federal states (Bavaria, Rhineland-Palatinate, Saarland, and Schleswig-Holstein) was conducted in 2004. Schools were selected randomly from the databases on the respective education web servers. The survey was approved by the departments of education and each principal was asked for permission to send questionnaires to his or her school. If the principal agreed, a certain number of questionnaires and one pre-paid, self-addressed enveloped was mailed to the respective school. Each teacher decided individually whether he or she would like to participate. Teachers of the same school were asked to resend the completed questionnaires together and anonymously. In May 2004 questionnaires were sent to 111 schools. A reminder notice was mailed to all schools shortly before the summer break. Questionnaires were returned by August 2004.

### 5.3.2 Participants and rate of return

At least 88 schools[4] and 240 chemistry teachers[5] participated in the survey. Table 5.1 summarizes the rate of return for each federal state.

Considering that the survey coincided with the busy end of the school year and that teachers volunteered to participate without any project involvement, the rate of return of 41.5% can be considered as high. The large number of participants indicates widespread interest for the improvement of texts for chemistry

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[4] Three questionnaires were returned separately. Due to anonymity we could not determine whether we received an extra envelope from the corresponding school. Thus, at least 88 and at most 91 schools participated.

[5] Not all participants completed all items so that the number of subjects included into the calculations varies. Except of the open-ended question there were more than 200 valid answers per item.

| Federal State | Number of schools receiving questionnaires | Number of mailed questionnaires | Number of returned questionnaires | Rate of return |
|---|---|---|---|---|
| Bavaria | 28 | 160 | 65 | 40.6% |
| Rhineland-Palatinate | 27 | 144 | 78 | 54.2% |
| Saarland | 27 | 146 | 45 | 30.8% |
| Schleswig-Holstein | 29 | 129 | 52 | 40.3% |
| Total | 111 | 579 | 240 | 41.5% |

Table 5.1: Rate of return of the questionnaires.

instruction.

The majority of participating teachers were aged 51 to 60 ($<$ 31 y. 6%; 31-40 y. 24%; 41-50 y. 26%; 51-60 y. 38%; $>$ 60 y. 6%). About 60% of the teachers were male. Biology was the most frequent second subject with 73%, followed by mathematics with 11%.

### 5.3.3 Instruments

A paper and pencil questionnaire was developed to be completed by the teachers. The questionnaire included items asking for which purpose texts are used as well as how they are integrated into teaching. Despite the claim for more active text work, studies on physics showed that texts are mostly used for revision, often at home. For investigating whether this pattern also prevails in chemistry classes, we used items related to the active use of texts in the classroom (practicing reading strategies, using texts during the lesson) as well as items referring to the use of texts for homework. To measure the overall satisfaction with textbook texts, the teachers were asked to evaluate general items, e.g., how texts impart conceptual knowledge. We further sought to determine factors of text design that are important to teachers. Therefor, items on special text features were used which referred to the four dimensions of Langer et al.'s (1974) concept, to students' ideas, and to learning aids. Teachers were also asked to assess students' interest in reading and to provide some personal data. Items were scored on a 4-point scale (with the exception of the frequency of text use). Additionally, teachers could answer to an open-ended question asking for suggestions how to improve textbook texts. All questions referred to chemistry classes of secondary level I.

### 5.3.4 Statistical methods

For investigating the first research question on how texts are used in chemistry instruction, teachers were asked how often and for what purpose they actually use texts in their teaching. Descriptive analyses were performed on these items[6]. We further looked for typical patterns of text use. An explorative factor analysis of the items that asked how texts are integrated into instruction (example item: "I present to the students questions on a text which they are asked to answer with the help of the text.") suggested three different scales. The factorial structure of the scales was confirmed by running a principle component analysis with varimax rotation. An oblique rotation was additionally conducted because some scales correlated weakly.

For investigating the second research question on how teachers assess current textbook texts and what their expectations are, the teachers were asked to assess whether the texts imparted conceptual knowledge and whether they were interesting and comprehensible for students. We additionally asked the teachers to rate the relevance of these aspects for text design from their perspective. Descriptive analyses were conducted on these items and paired t-tests (two-tailed) were used for testing for significant differences between the assessment and the expectations of the teachers. Factors that were relevant for both the assessment and the expectations were determined by explorative factor analyses of the items on

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[6] For the analyses of the data of this thesis, the statistical software packages GradeMap (Version 4.2.1, http://bearcenter.berkeley.edu/GradeMap), R (Version 1.9.1, http://www.r-project.org) and SPSS (Version 12.0G, SPSS Inc.) were used.

text design (example item: “The textbook texts address students’ experiences.”). The analyses revealed three principal factors. The factorial structure of the scales was confirmed by running principal component analyses with varimax rotation. Again, oblique rotations were additionally conducted due to the weak correlation of some of the scales.

The third research question asked for groups of teachers that differ in how they use texts in their teaching. For this analysis, we used two scales (N(0,1) standardized) which described different patterns of text use in chemistry instruction. Each observation was considered as a point $x$ in 2-dimensional Euclidean space. Cluster analysis was performed on these data. To determine the number of clusters and to confirm the validity of the resulting solution, different criteria were applied following Backhaus et al. (2003) and Moosbrugger & Frank (1992). Hierarchical clustering methods were used for identifying outliers (using single linkage) and for finding the optimal number of clusters in the data (using Ward). In both cases, the criterion was a strong increase of heterogeneity within the clusters with decreasing number of clusters. Euclidean distance was used as distance measure. A partitioning method (k-means) was eventually used for clustering the data. However, the solution of the k-means algorithm may depend on the order of points in the original dataset (Bortz 1999). We therefore implemented an algorithm that used k-means to compute cluster solutions based on random data permutations and randomly selected initial centers[7]. The best solution was selected by maximizing the following function (Hand et al. 2001),

$$B: \quad \text{Set of computed cluster solutions} \to \mathbb{R},\ C \mapsto \frac{bc(C)}{wc(C)},$$

where the within cluster variation, $wc$, and the between cluster variation, $bc$, are defined as follows (Hand et al. 2001),

$$\begin{aligned} wc(C) &= \textstyle\sum_{k=1,\ldots,K} \sum_{x \in C_k} ||x - r_k||^2, \\ bc(C) &= \textstyle\sum_{1 \le j < k \le K} ||r_j - r_k||^2, \quad j \neq k, \end{aligned}$$

with $K$ the number of clusters, $r_{k(j)}$ the cluster center of the $k(j)$th cluster, and $C_k$ the $k$th cluster.

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[7] The mean values of the Ward clusters were used as starting values for the iteration.

For investigating the degree of homogeneity within the clusters, we calculated the ratio of the variance of each variable $i$ within a particular cluster $C_k$ to the variance of the entire sample ($\frac{Var(i,C_k)}{Var(i)}$). The stability was evaluated by running the algorithm several times and comparing the cluster solutions. Additionally, random sub-samples were drawn from the full data set (50%, 75%, 90%) and cluster analyses were performed on each sample. This process was repeated three times yielding nine sub-samples. The cluster membership of the cases within the sub-samples was compared to the membership of the original solution (see Levine et al. 2001).

## 5.4 Results

### 5.4.1 How do chemistry teachers use texts in their teaching?

*Frequency of text use*

Table 5.2 presents how often chemistry teachers use texts in a class of secondary level I[8]. In general, chemistry teachers rarely integrate texts into their teaching. About 40% stated to use texts at most two times per term (half-year). Less than a third of the participants use texts more than once a month.

*Purpose of text use*

The chemistry teachers stated to use texts mostly for revision and consolidation, and to a lesser degree for showing connections to everyday life. There is probably an overlap between those two items, since consolidation phases are often used for showing everyday life applications. Texts are rarely used for the introduction into a topic or for working on new subjects. Table 5.3 shows the mean values and standard deviations of the different items (“I do not agree” (1) to “I agree” (4)[9]; see Table A.1 for the original items). The high standard deviations suggest a large diversity among the chemistry teachers.

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[8] The scale ranged from “Once a year” to “Each lesson”. Two participants explicitly stated “Never”, though.

[9] “trifft nicht zu” (1) to “trifft zu” (4)

| Frequency of text use | N | Percentage | Cumulative percentage |
|---|---|---|---|
| Never/Once a year | 14 | 6.3% | 6.3% |
| Once every six months | 25 | 11.3% | 17.6% |
| Once every three months | 51 | 23.1% | 40.7% |
| Once a month | 60 | 27.1% | 67.9% |
| Once every two weeks | 46 | 20.8% | 88.7% |
| Once a week | 22 | 10.0% | 98.6% |
| Each lesson | 3 | 1.4% | 100.0% |
| Total | 221 | 100.0% | |

Table 5.2: Frequency of text use in a chemistry class of secondary level I. Number of valid cases per category, percentage of valid cases per category, cumulative percentage.

| Purpose of text use – items | M | (SD) |
|---|---|---|
| I use texts for working on new subjects. | 2.03 | (± 0.80) |
| I use texts for the introduction into a topic. | 2.08 | (± 0.84) |
| I ask my students to read texts for the purpose of revision and consolidation. | 2.76 | (± 0.98) |
| I use texts for showing connections between school chemistry and everyday life. | 2.62 | (± 1.01) |

Table 5.3: Purpose of text use. Mean value (M), standard deviation (SD).

*Patterns of text use in chemistry classes*

The factor analysis revealed three factors which corresponded to the dimensions of text use discussed above. Table 5.4 presents the factorial structure of the scales. Orthogonal and oblique rotation yielded the same results (see Table A.2 for the original items).

The first scale "practicing reading strategies" included items referring to common reading techniques. The other two scales described different ways of how to use texts in chemistry teaching: "texts in the classroom" and "texts for homework".

The scale "texts in the classroom" measures how texts are integrated actively into the regular chemistry classroom. Students receive textual material as a source of information, e.g., while working at learning stations. They are asked to rephrase the content of a text in their own words, and they are presented with questions which they have to answer with the help of a text. They either work individually or cooperate in small groups.

In contrast, the scale "texts for homework" describes the use of texts outside the classroom community. Here, students are asked to use texts at home for revision and consolidation, or for catching up when they have missed school due to illness or when they have difficulties in following the class.

The internal consistency reliability of the subscales was estimated using Cronbach's $\alpha$ yielding acceptable indices from .67 to .83. The correlation among the scales was relatively low[10] ("practicing reading strategies" and "texts for homework", r = .24**; "texts for homework" and "texts in the classroom", r = .08 ns). As expected, the correlation between "practicing reading strategies" and "texts in the classroom" was higher with r = .49**.

Table 5.5 summarizes the characteristics of the scales for the use of texts in chemistry instruction.

The items included in the scales were rated by the teachers from "I do not agree" (1) to "I agree" (4)[11]. The mean value of 2.42 (± 0.77) for the first scale indicates that chemistry instruction does not focus on practicing reading strate-

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[10] **p $<$ .001; Partial correlation controlling for the respective third variable.

[11] "trifft nicht zu" (1) to "trifft zu" (4)

| **Item text** | **Factors** | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| I ask the students to divide a longer text into paragraphs. | **.753** | | |
| I ask the students to use a systematic way for working on longer texts (e.g., scan the text, identify paragraphs, ask questions about the text, review the text ...). | **.751** | .324 | |
| I ask the students to generate their own questions about a text. | **.716** | | |
| I ask the students to find headings/keywords for individual paragraphs. | **.710** | | |
| I ask the students to identify and highlight important terms and passages of a text. | **.709** | .344 | |
| In my classroom the students read texts silently in individual work. | | **.759** | |
| When the students work in pairs or groups (e.g., at learning stations), they are given texts as information source. | | **.741** | |
| I encourage the students to cooperate in small groups for working on a text (e.g., for answering questions on the text). | | **.724** | |
| I present to the students questions on a text which they are asked to answer with the help of the text. | .321 | **.655** | |
| I ask the students to rephrase the content of a text in their own words. | | **.643** | |
| I ask the students who missed classes due to illness to catch up with the help of the textbook. | | | **.743** |
| I tell the students which chapters of the textbook or other texts they can use for preparing for an exam. | | | **.680** |
| I ask the students who have comprehension difficulties during classroom instruction to reread the content in the textbook. | | | **.654** |
| I tell the students which chapters of the textbook or other texts they can use for doing their written homework. | | | **.634** |
| I encourage the students to use texts for reviewing a topic at home. | .350 | | **.504** |

Table 5.4: Principal component analysis with varimax rotation for the use of texts in chemistry instruction. Factor loadings for the three-factor solution. Factor loadings $<0.3$ were suppressed. Loadings in bold indicate the assignment of the items to the factors.

| Name of scale | No. of items | Cronbach's $\alpha$ | M | (SD) | Min | Max |
|---|---|---|---|---|---|---|
| Practicing reading strategies | 5 | .83 | 2.42 | (± 0.77) | 1.00 | 4.00 |
| Texts in the classroom | 5 | .81 | 2.79 | (± 0.73) | 1.00 | 4.00 |
| Texts for homework | 5 | .67 | 2.97 | (± 0.61) | 1.40 | 4.00 |

Table 5.5: Characteristics of the scales for the use of texts in chemistry classes. Name of scale, number of items, internal consistency (Cronbach's $\alpha$), mean value (M), standard deviation (SD), minimum (Min), maximum (Max).

gies. Looking at the other two scales, "texts in the classroom" (2.79 ± 0.73) and "texts for homework" (2.97 ± 0.61), we find mean values higher than the value of 2.50, which would have been expected if teachers were equally distributed among the four levels of the scale ($p < .001$). Homework seems to be the most important domain for texts.

### 5.4.2 How do teachers assess current textbook texts and what are their expectations?

Each item referring to specific text features was evaluated twice by the teachers. First, they assessed the texts of the textbook which was used at their school on a 4-point scale from "I do not agree" (1) to "I agree" (4)[12]. Then, they rated the relevance of these features for the design of a textbook text (from "unimportant" (1) to "important" (4)[13]).

*Degree of interestingness and comprehensibility of textbook texts from the teachers' perspective*

The chemistry teachers rather disagreed that textbook texts are interesting for students (M = 2.20 (± 0.62)), or that students can easily acquire new knowledge from texts by themselves (M = 2.11 (± 0.69)). Only when texts are

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[12] "trifft nicht zu" (1) to "trifft zu" (4)

[13] "unwichtig" (1) to "wichtig" (4)

| | **Assessment** | | **Expectation** | | **t-test** | |
|---|---|---|---|---|---|---|
| Item text | M | (SD) | M | (SD) | t | p |
| Textbook texts are interesting for students. | 2.20 | (± 0.62) | 3.64 | (± 0.59) | -25.38 | $<$ .001 |
| Students have no comprehension difficulties when reading a text with familiar content. | 2.92 | (± 0.76) | 3.76 | (± 0.46) | -14.11 | $<$ .001 |
| Students have no comprehension difficulties when reading a text with new content (i.e., for working on new contents in individual work or teamwork). | 2.11 | (± 0.69) | 3.48 | (± 0.65) | -23.07 | $<$ .001 |

Table 5.6: Assessment of and expectations for textbook texts from the teachers' perspective. Item text, mean value (M), standard deviation (SD), two-tailed paired t-test.

used for revision students do not seem to have large comprehension difficulties (M = 2.92 (± 0.76)). The teachers thought that all three aspects are important for the design of textbook texts, and the discrepancies between the assessment of the teachers and their expectations were significant (see Table 5.6, and Table A.3 for the original items).

### *Potential of textbook texts to impart conceptual knowledge from the teachers' perspective*

The participating teachers rather disagreed that textbook texts impart cross-topic understanding (M = 2.22 (± 0.74)). They only moderately agreed to the statement that textbook texts provide not only factual but also comprehensive knowledge (M = 2.62 (± 0.76)), and that they support students in overcoming their comprehension difficulties (M = 2.46 (± 0.62)). All three aspects were rated as relevant for the design of textbook texts, and the discrepancies between the assessment of the teachers and their expectations were significant (see Table 5.7, and Table A.4 for the original items).

| | **Assessment** | | **Expectation** | | **t-test** | |
|---|---|---|---|---|---|---|
| Item text | M | (SD) | M | (SD) | t | p |
| I think that textbook texts support students in overcoming comprehension difficulties. | 2.46 | (± 0.62) | 3.60 | (± 0.53) | -22.97 | $< .001$ |
| I think that textbook texts impart not only factual but also comprehensive knowledge. | 2.62 | (± 0.76) | 3.70 | (± 0.52) | -19.63 | $< .001$ |
| I think that textbook texts impart cross-topic understanding. | 2.22 | (± 0.74) | 3.36 | (± 0.68) | -18.00 | $< .001$ |

Table 5.7: Assessment of and expectations for textbook texts from the teachers' perspective. Item text, mean value (M), standard deviation (SD), two-tailed paired t-test.

*Factors of text design that are relevant for teachers' assessment of and their expectations for textbook texts*

The factor analyses revealed three dimensions that were relevant for teachers with regard to both their assessment of and their expectations for textbook texts. Table 5.8 presents the factorial structure of the scales. Orthogonal and oblique rotation yielded the same results (see Table A.5 for the original items).

We expected to find four scales referring to the dimensions of the concept of Langer et al. (2002). Instead, the factor analyses revealed only one factor comprising items on simplicity of language, conciseness, and structure (A1 and E1). This scale can be interpreted as describing the "readability" of a text. The second scale referred to "students' experiences" (A2 and E3) and comprised, as expected, items related to students' experiences and ideas. Items of the categories "learning aids" and "prompts for thinking" were combined in the third scale (A3 and E2). These items referred to text elements which support students in actively constructing knowledge. The scale was therefore called "support for knowledge construction". The scales were internally consistent with Cronbach's $\alpha$ coefficients of .63 to .80. The correlation among the scales was relatively low[14] ($r = .15$ to .40 for the assessment and $r = .20$ to .33 for the expectations).

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[14] $p < .05$; Partial correlation controlling for the respective third variable.

| **Item text** | **Factors** | | | | | |
|---|---|---|---|---|---|---|
| | **Assessment (1. Factor analysis)** | | | **Expectation (2. Factor analysis)** | | |
| | A1 | A2 | A3 | E1 | E2 | E3 |
| The sentences are simple (e.g., no complex subordinate clauses). | **.723** | | | **.749** | | |
| The textbook texts include no minor aspects or irrelevant information. | **.706** | | | **.595** | | |
| The sentences are short. | **.704** | | | **.746** | | |
| The textbook texts are divided into clear paragraphs. | **.637** | | | **.539** | | .357 |
| The number of technical terms is appropriate for the knowledge of the students. | **.621** | | | **.621** | | |
| The textbook texts have no content gaps or logical gaps. | **.554** | | | **.530** | | |
| The textbook texts address students' experiences. | | **.838** | | | .310 | **.641** |
| The textbook texts provide examples which tie in with students' everyday experiences. | | **.819** | | | | **.772** |
| The textbook texts address experiences and ideas with which students are familiar from everyday life. | | **.771** | | | | **.757** |
| The textbook texts are preceded by introductory questions. | | | **.646** | | **.745** | |
| The textbook texts are preceded by a list of learning goals. | | | **.644** | | **.729** | |
| The textbook texts are preceded by a paragraph which succeeds in building a bridge from students' prior knowledge to the contents presented in the text. | | | **.638** | | **.621** | .383 |
| The textbook texts address misconceptions which many students have or develop about the respective topic. | | | **.582** | | **.653** | |
| The textbook texts include questions/statements which arise students' curiosity about the contents presented in the following. | | .331 | **.447** | | **.573** | |

Table 5.8: Principal component analysis with varimax rotation for teachers' assessment of and their expectations for textbook texts. Factor loadings for the three-factor solution. Factor loadings <0.3 were suppressed. Loadings in bold indicate the assignment of the items to the factors.

| Name of scale | No. of items | A/E | Cronbach's $\alpha$ | M | (SD) | Min | Max |
|---|---|---|---|---|---|---|---|
| Readability | 6 | A | .75 | 3.03 | (± 0.45) | 1.33 | 4.00 |
| | | E | .71 | 3.52 | (± 0.40) | 2.33 | 4.00 |
| Students' experiences | 3 | A | .80 | 2.49 | (± 0.58) | 1.00 | 4.00 |
| | | E | .74 | 3.53 | (± 0.48) | 1.67 | 4.00 |
| Support for knowledge construction | 5 | A | .63 | 1.85 | (± 0.48) | 1.00 | 3.50 |
| | | E | .73 | 2.91 | (± 0.56) | 1.40 | 4.00 |

Table 5.9: Characteristics of the scales for teachers' assessment of and their expectations for textbook texts. Name of scale, number of items, assessment/expectation (A/E), internal consistency (Cronbach's $\alpha$), mean value (M), standard deviation (SD), minimum (Min), maximum (Max).

The teachers assessed only the "readability" as good. The addressing of "students' experiences" was evaluated as average and the implementation of "support of knowledge construction" as low. Regarding the expectations, the teachers rated all aspects above average, especially valuing "readability" and "students' experiences". "Support for knowledge construction" was not regarded as important as the other two scales. The discrepancies between the assessment of the teachers and their expectations were particularly high for "support for knowledge construction" and "students' expectations", and significant for all three scales ($p < .001$). Table 5.9 summarizes the characteristics of the scales.

These results were supported by the answers to the open-ended question asking for suggestions how to improve textbook texts. The teachers most frequently expected textbooks to refer more to everyday life and to students' experiences (30% of $N_{tot} = 73$) as well as to have more workbook character (e.g., problems for self-study, fill-in exercises; 25% of $N_{tot} = 73$). About 20% (of $N_{tot} = 73$) of the teachers commented on the language level and emphasized that texts should use a clear and precise language including a moderate use of technical terms. The teachers also asked for short and comprehensible sentences, but cautioned against a flattening of language.

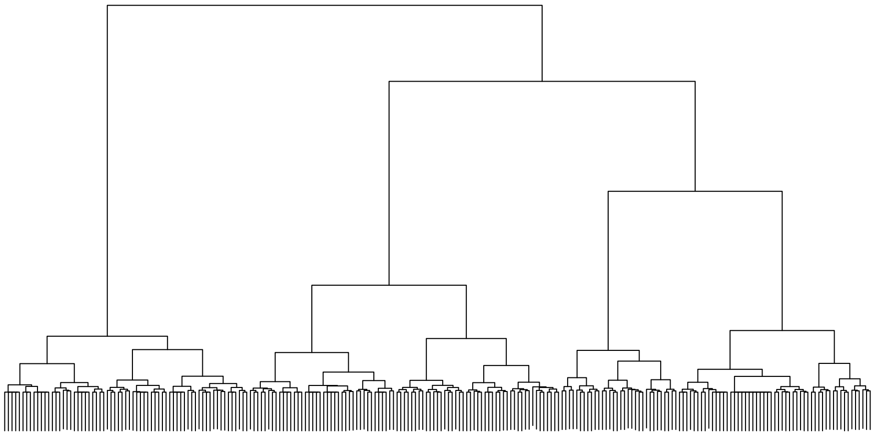

Figure 5.1: Dendrogram produced by Ward's method. Clustering was based on the variables "texts in the classroom" and "texts for homework". The 4-cluster solution showed a large increase in heterogeneity compared to the 5-cluster solution.

### 5.4.3 Are there groups of teachers that differ in how they use texts in their teaching? What are characteristics of these groups?

The N(0,1) standardized variables "texts in the classroom" and "texts for homework" were used for clustering. Three outliers were identified (1.25% of the sample) and excluded from further analyses. After eliminating the outliers, variables were re-standardized.

Figure 5.1 shows the dendrogram of Ward's method indicating a five cluster solution. A further merging of clusters would have resulted in a large increase of the heterogeneity of the clusters. A five-cluster solution was therefore specified for the k-means algorithm ($K = 5$).

Regarding the homogeneity scores, all values were below .50, seven of them even below .25, which indicated homogeneous clusters (see Figure 5.2).

Concerning the second evaluation criterion, the clusters were found to be

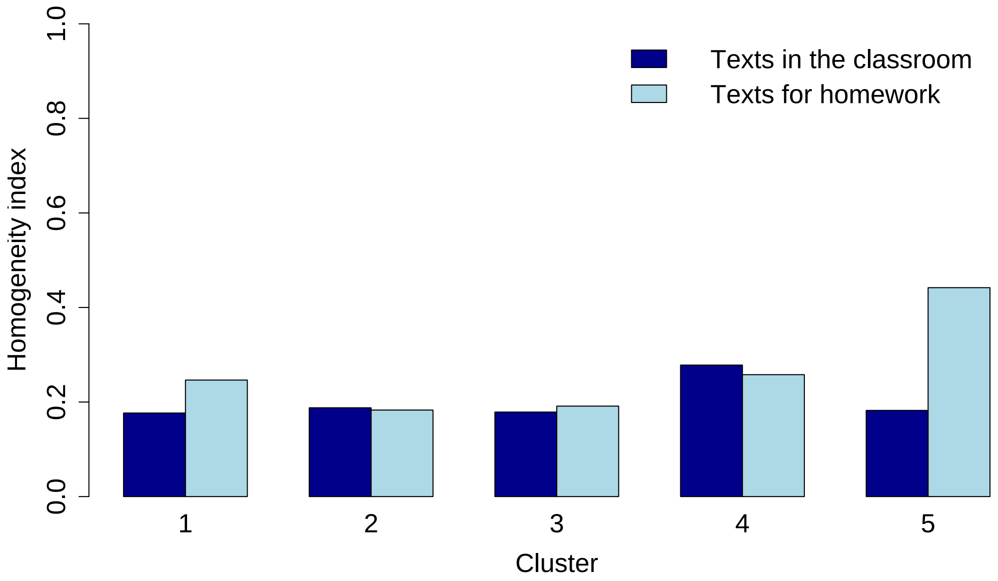

Figure 5.2: Homogeneity indices for the 5-cluster solution.

very stable. The iterative algorithm was run several times and yielded the same clustering solution. The sub-samples matched the original cluster structure with a hit rate of 90.8% to 99.5%.

### Describing the clusters

Figure 5.3 shows the clustering and the cluster centers for the 5-cluster solution.

**Cluster 1: Texts for homework.** Cluster 1 was the largest cluster with 61 chemistry teachers. The group comprised teachers who seldom use texts actively in the classroom, but rather for homework.

**Cluster 2: Texts for homework and in the classroom.** Cluster 2 included 58 chemistry teachers who were distinguished by their high values for the use of texts both in the classroom and for homework.

**Cluster 3: Texts in the classroom.** Cluster 3 contained 53 chemistry teachers who work actively with texts in the classroom but who seldom use texts for homework.

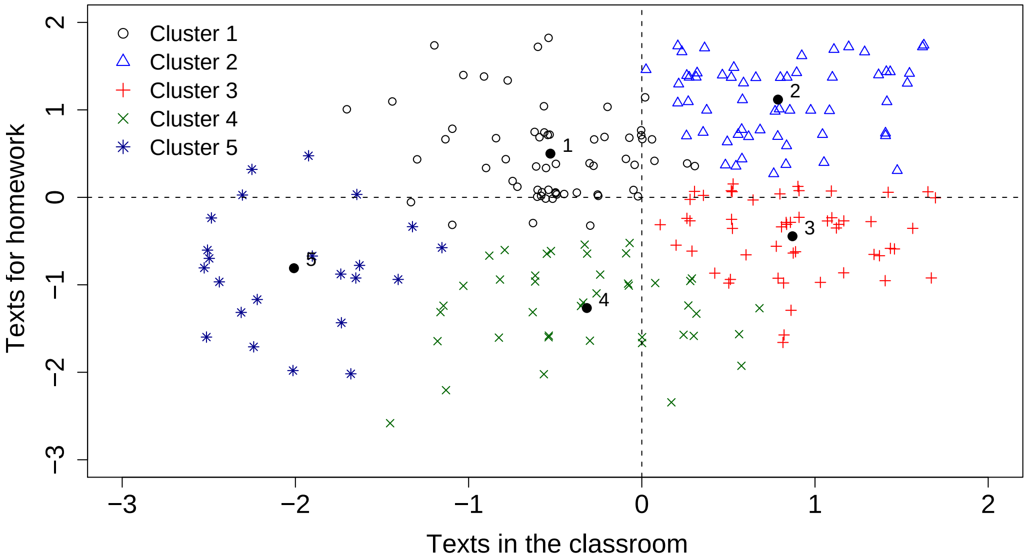

Figure 5.3: 5-cluster solution. N(0,1) standardized values. Cluster centers are marked by numbers. All data points were jittered slightly (by adding a random error term drawn from the (0,0.05) normal distribution) so that overlying points could be seen in the figure.

**Cluster 4: Rare use of texts, especially for homework.** Cluster 4 comprised 42 chemistry teachers who seldom use texts in general, but especially not for homework.

**Cluster 5: Rare use of texts, especially in the classroom.** Cluster 5 was the smallest group with only 23 chemistry teachers. These teachers seldom use texts in general, but especially not in the classroom.

#### Comparison of the clusters

Comparing clusters on their assessment of textbook texts, we found that teachers of cluster 1 showed relatively high ratings, whereas teachers of cluster 3 and 4 seemed to be particularly critical. Figure 5.4 presents the mean values of the clusters for different standardized variables on text assessment. There were significant differences among some groups for three variables ("support in overcoming comprehension difficulties", "impart not only factual but also comprehensive knowledge", "support for knowledge construction"; ANOVA, Post-Hoc: Scheffé, $p < .05$).

The expectations for textbook texts also differed among the groups (see Figure 5.5). It is striking that the teachers of those clusters that were characterized by active textwork in the classroom (cluster 2 and 3) rated nearly all aspects as more relevant than teachers of the other groups.

The question of whether students enjoy working with texts was also answered differently by teachers in distinct clusters (see Figure 5.6). Cluster 2 and particularly cluster 3 showed positive values compared to the other groups, whereas cluster 4 and particularly cluster 5 rated the interest of students comparatively negative. The differences between group 5 and 1, 2, and 3, respectively, were significant (ANOVA, Post-Hoc: Scheffé, $p < .01$). In general, teachers assessed students' interest in reading as low. They did not think that students enjoy working with texts in chemistry classes[15] ($M = 2.24$ (± 0.65)) or that students actually read texts about chemistry topics outside of school[16] ($M = 1.69$ (± 0.69)).

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[15] Original item in German: "Die Schüler/-innen arbeiten gerne mit Texten."

[16] Original item in German: "Ich bin der Meinung, dass die Schüler/-innen auch außerhalb des Chemieunterrichts Texte mit chemischem Inhalt lesen."

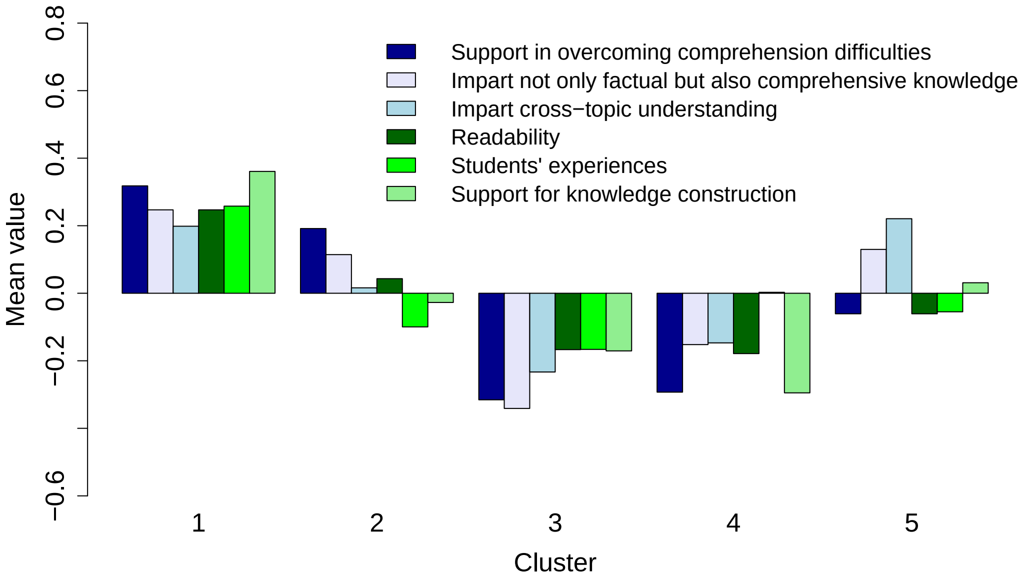

Figure 5.4: Assessment of textbook texts by cluster. N(0,1) standardized values.

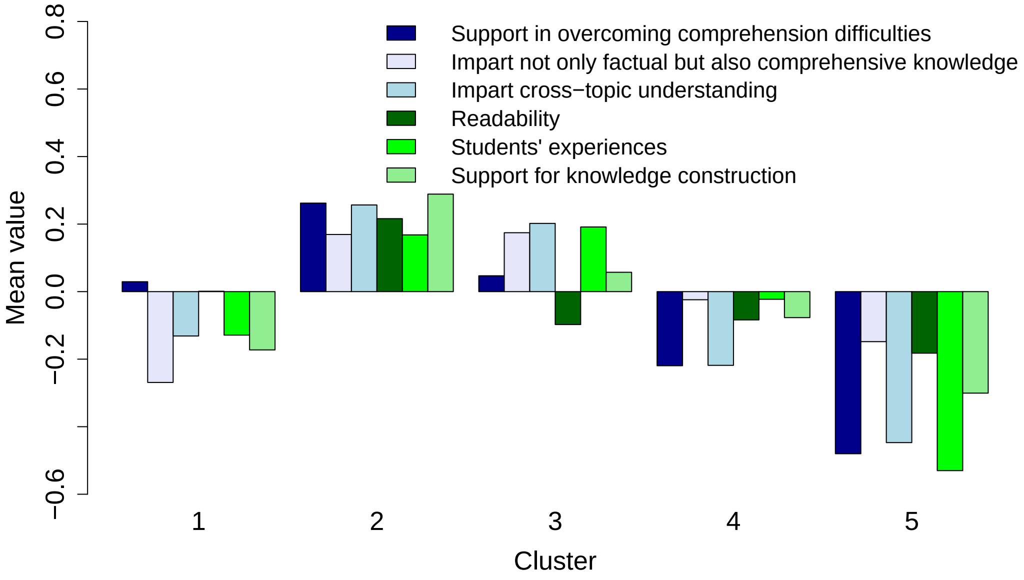

Figure 5.5: Expectations for textbook texts by cluster. N(0,1) standardized values.

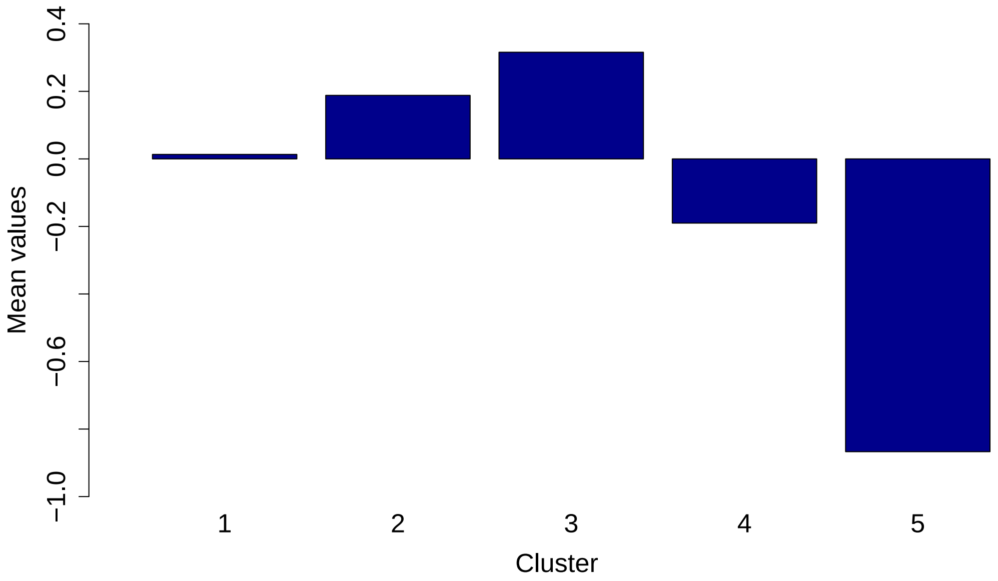

Figure 5.6: Assessment of students' interest in reading in chemistry classes by cluster. N(0,1) standardized values ("Students enjoy working with texts").

## 5.5 Summary and discussion

Science education is challenged to contribute to the development of reading literacy both for preparing students to become lifelong learners and for ensuring student-centered instruction. On the one hand, reading literacy is a key determinant for independent learning and it is pivotal for successfully communicating and participating in society. On the other hand, student-oriented teaching methods heavily rely on students' ability to read, understand, and learn from science texts. Experts like science teachers are needed to guide students in becoming scientifically literate. However, there is only little knowledge on how chemistry teachers use textbooks or other texts in the classroom. The reported study investigated how chemistry teachers actually use texts in their teaching as well as how satisfied they are with current textbook texts.

*How do chemistry teachers use texts in their teaching?*

Results of this study show that chemistry teachers rarely integrate texts into their teaching. Less than a third of the participants stated that they use texts more than once a month in a class of secondary level I. Homework was found to be the most important domain for texts, especially in the context of revision. Practicing reading strategies seems to play a rather minor role. These findings match the results of studies on the use of texts in physics instruction (Bleichroth et al. 1987, Merzyn 1994, Schäfer 1983, Starauschek 2003). Considering texts as an integral part of student-oriented teaching methods (e.g., students work at learning stations or on their own research projects), the infrequent use of texts can be interpreted as an indicator of the prevalence of teacher-centered instruction characterized by directed student-teacher discussions. It is widely agreed, however, that effective teaching requires a shift towards more applied, problem-based, and student-centered teaching approaches (Gräsel & Parchmann 2004, Prenzel et al. 2001). Professional development trainings might address this problem, such as courses on student-oriented teaching methods with a particular focus on chemistry instruction. Concrete suggestions of how to work with students on science texts and how to integrate textual material effectively should be given. In this context, it might be problematic that teachers at Gymnasiums, in contrast to teachers at Real- or Hauptschule, appear to prefer content based courses for their professional development as the interview study of Daus et al. (2004) suggests.

*How do teachers assess current textbook texts and what are their expectations?*

With regard to the assessment of textbook texts, teachers particularly criticized those aspects that are important for self-directed and differentiated learning. For example, teachers rather disagreed that textbook texts were interesting for students or that students were able to acquire new knowledge from the texts by themselves. This result is critical in connection with the observation that chemistry classes seem to offer little exercise in working on science texts and in learning from them. Even if teachers seldom use texts in the classroom, students are nevertheless often dependent on reading textbooks. For example, textbook texts are important sources when students missed classes due to illness, when they could not follow the instruction during the lesson, when their lesson notes are insufficient, or when they want to get more information on a special topic.

Regarding teachers' assessment of and expectations for textbook texts, we found three dimensions that seem to be relevant, namely "readability" (simplicity of language, conciseness, inner and outer structure), "students' experiences" and "support for knowledge construction". Only the dimension of "readability" was assessed as good. In other words, from the teachers' point of view, simple language and structure are not sufficient for the design of student-appropriate texts. This aspect also became apparent from the fact that the assessment of the teachers differed significantly from their expectations for all three dimensions, but especially for the scales "students' experiences" and "support for knowledge construction".

Overall, it was found that, from the teachers' perspective, textbook texts need improvement of important aspects such as the integration of learning aids. Teachers expect textbook texts to focus more on students' everyday ideas and experiences.

*Are there groups of teachers that differ in how they use texts in their teaching?*

For grouping teachers by the extent to which they use texts in the classroom and for assigning homework, a cluster analysis was conducted using the variables "texts in the classroom" and "texts for homework". Five clusters were identified comprising teachers who use texts mainly for homework, strongly both in the classroom and for homework, often in the classroom but rarely for homework, generally seldom, and especially seldom in the classroom or for homework, respectively. Clusters were compared regarding the satisfaction of the teachers with textbook texts and regarding their assessment of students' interest in reading.

The distinct clusters differed from each other in their assessment of as well as in their expectations for textbook texts. The discrepancies between teachers' assessment and their expectations can be interpreted as their degree of satisfaction. It is striking that teachers who stated to work actively with texts in the classroom were more dissatisfied than their colleagues. This finding indicates that current textbooks do not offer texts that are appropriate for being integrated into classroom teaching. The interest of students for reading in chemistry classes was overall assessed as low by the teachers. Teachers, who stated to work actively with texts in the classroom, rated students' interest higher than those, who stated to rarely use texts in their teaching. However, it has to be considered that students' interest in working with texts was assessed by the teachers. It is unlikely to expect that teachers assess their students' inclinations contrary to their own teaching habits. Further studies have to investigate if working actively with science texts actually enhances students' interest in reading. This question is particularly interesting with regard to the PISA study, which revealed that German students have a rather poor attitude towards reading (Artelt et al. 2001).

Finally, we mention that the reported results are based on an explorative pilot study and that more than two thirds of the teachers referred to the same textbook in their assessment. Further surveys of chemistry teachers have to verify the findings of this study.

Overall, the study gave valuable insight into aspects that teachers appreciate about current textbook texts as well as into aspects that need improvement from a practitioner's perspective. The results are used in Chapter 7 for the design of a conceptual change text for chemistry teaching. The study further indicated that chemistry teachers rarely work with texts in the classroom. This pattern is challenged by the need for a more student-centered instruction and for an interdisciplinary approach for fostering reading literacy.

# 6

# Study 2 – Chemistry textbooks as a resource for lesson planning: How do they address common ideas of students?

The design of conceptual change texts for chemistry textbooks can influence teaching practice in different ways. On the one hand, textbook texts can be used by students as learning aids. In this context, it is important that textbook texts adhere to basic principles of conceptual change instruction since the addressing of common misconceptions is regarded as key to fostering conceptual understanding as discussed in Chapter 2 and Section 3.4. On the other hand, textbook texts can be used by teachers as teaching aids. A survey of Daus et al. (2004) suggests that textbooks are one of the most important media that are used by chemistry teachers for planning their teaching. The integration of conceptual change texts into textbooks might thus offer an opportunity to provide teachers with information about common alternative ideas and with practical suggestions how these ideas might be addressed.

The first study presented in this chapter ties in with the survey of Daus et al. (2004) by investigating the role of textbooks in the lesson planning of chemistry Gymnasium teachers. Knowledge about the relevance of textbooks for the preparation of teaching gives a first estimate of the potential influence that conceptual change texts might have on actual teaching practice.

The second study presented in this chapter refers to the first aforementioned aspect and investigates how textbook texts take common misconceptions into account. Investigating this question is not only important for obtaining information about the status quo of currently used learning material, but also for the research presented in the following chapter where a conceptual change text is designed and evaluated. As Bransford et al. (2000*c*, p. 256) argue, the development of new educational material should "begin with existing curricula and modify them to better reflect key principles of learning". We conducted a qualitative analysis of texts on the introduction of the particle model found in two popular textbooks. The intention was to determine text elements that can be adopted for the conceptual change text and elements that need to be changed. Additionally, with regard to a fair comparison in the experiment presented in Chapter 7, we wanted to identify a traditional textbook text for the control group which does address at least some common ideas of students.

After presenting results of the analysis of current textbook texts, a section of the conceptual change text developed in Chapter 7 is presented, and design criteria are explained in order to highlight the difference between currently used material and texts which are composed according to principles of conceptual change instruction[1].

## 6.1 Textbooks as a resource for lesson planning

As part of the study "Texts in chemistry classes" presented in the preceding chapter we asked chemistry teachers for the role of textbooks in their lesson planning. The following research questions were investigated: How important are chemistry textbooks compared to other sources? Which aspects of lesson planning are influenced by chemistry textbooks?

### 6.1.1 Method

The procedure, participants and instrument of the survey are described in detail in Section 5.3.1, 5.3.2 and 5.3.3, respectively. Besides the items discussed in Section 5.3.3, the questionnaire comprised an additional section referring to the

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[1] An article with main results of the study presented in this chapter has been submitted for publication (Beerenwinkel et al. 2006).

use of textbooks for lesson planning for chemistry classes of secondary level I. The teachers were first asked to imagine the situation of planning a new teaching unit for which they have no materials yet. They then assessed the importance of different sources for planning such a unit on a 4-point scale from "unimportant" (1) to "important" (4)[2]. Afterwards, the teachers evaluated different items which referred to concrete aspects of lesson planning that might be influenced by textbooks (on a 4-point scale from "I do not agree" (1) to "I agree" (4)[3]).

### 6.1.2 Results

Figure 6.1 visualizes how many teachers answered "rather important"/"important" or "rather unimportant"/"unimportant" to the question, "For planning a new teaching unit, how important are the following sources?" More than 85% of the teachers stated that syllabi and textbooks are (rather) important sources for planning a new teaching unit. In contrast, more than half of the participating teachers answered that educational journals, Internet, and scientific journals play a (rather) unimportant role in their preparation.

Figure 6.2 shows the results of the question that asked for the relevance of textbooks for specific aspects of lesson planning (see Table A.6 for the original items). Overall, about 90% of the teachers (rather) agreed that textbooks provide suggestions on content-specific aspects for new teaching units. Almost as many teachers (rather) agreed that they address everyday life aspects in their teaching which are mentioned in textbooks. More than half of the participants agreed that they use textbooks for suggestions on the sequence of the unit as well as for the texts which the students are supposed to write down in their chemistry notebooks. A somewhat smaller portion of 47% (rather) agreed to use explanations from textbooks in their teaching.

The results of the study presented in Chapter 5 suggest that teachers seldom integrate textbook texts into their teaching. The teachers rather disagreed that textbook texts are interesting for students or that students can easily acquire new knowledge from texts by themselves. Textbooks seem thus to play a rather minor

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[2] "unwichtig" (1) to "wichtig" (4)

[3] "trifft nicht zu" (1) to "trifft zu" (4)

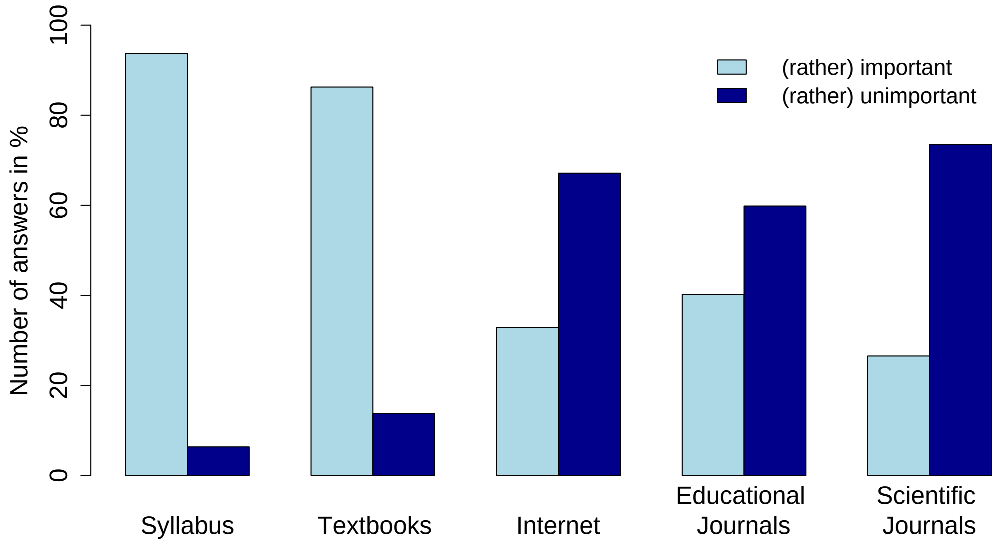

Figure 6.1: Distribution of answers to the question: For planning a new teaching unit, how important are the following sources?

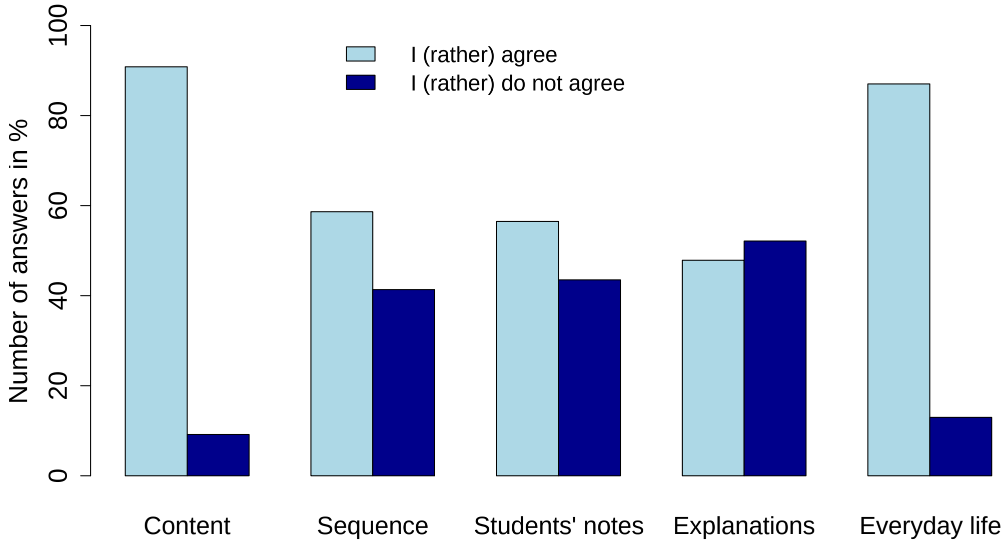

Figure 6.2: Distribution of answers to the question: Which specific role do textbooks play for planning a new teaching unit?

role as learning aids in chemistry classes. Regarding the relevance of textbooks as teaching aids, in contrast, the present results highlight the importance of textbooks for the lesson planning of chemistry teachers.

## 6.2 Addressing of students' ideas in textbook texts

The relevance of addressing students' ideas has been discussed in detail in preceding chapters. Here, only a selection of aspects presented in Chapter 2 is outlined in order to provide a short framework for the following textbook analysis.

For learning with understanding it is essential that instruction ties in with students' prior knowledge and thus also with their individual ideas about chemical concepts. These ideas might be brought into the classroom or they may develop under instruction. In many cases, the ideas are not consistent with the scientific view and they are therefore called "misconceptions", "alternative ideas", or "students' ideas". How misconceptions evolve and how they can be addressed is the subject of conceptual change research. The notion of conceptual change does not mean that prior ideas are "deleted" and replaced by scientific ones, but it is assumed that different ideas can co-exist (Duit 1999). Conceptual change is interpreted as a process in which not necessarily the content of the prior idea changes but the status or acceptance of this idea in comparison to the scientific one (Hewson et al. 1998). For example, the notion that a substance vanishes when burnt is sensible and useful in a lot of everyday life situations. However, the view can entail problems when one wants to understand the impact of combustion on the greenhouse effect. Fostering metaconceptual understanding is thus regarded as pivotal for lasting conceptual change (e.g., Vosniadou & Ioannides 1998). On the one hand, students should develop metaconceptual awareness, i.e., they should know different concepts and should be aware of their strengths and limitations. On the other hand, this knowledge should result in the competency to apply the different concepts appropriately according to the respective context. In order that students prefer scientific concepts to their pre-instructional ideas, at least in certain situations, they must become aware of the limits of their ideas (Posner et al. 1982). Therefor, a phenomenon is often presented, which contradicts a common idea of students and thus constitutes an anomaly for them. The goal is to evoke a cognitive conflict which motivates the intended conceptual change process. Research has shown, however, that students do not always reorganize their knowledge when they are presented with an anomaly. Reasons for this are that students do not see or understand the anomaly and thus do not realize that there is a contradiction to their own ideas. Even if students understand the anomaly, they may reply to it in an "undesirable" way. For example, they might reinterpret the data, i.e., they may explain the phenomenon in a way which does not conflict with their ideas. They might also claim the data to be invalid, e.g., due to shortcomings of the experimental design (Chinn & Brewer 1998, Mason 2001). Thus, when a phenomenon is presented for producing a cognitive conflict, different aspects have to be taken into account. For example, it has to made sure that the intended conflict is clearly elaborated and emphasized. Besides these cognitive variables other factors such as the motivation of students or the classroom structure play an important role for effective conceptual change processes (Pintrich et al. 1993).

The textbook analysis presented here aims at investigating, for the case of the particle model, whether common misconceptions are addressed explicitly in chemistry textbook texts. We chose the particle model as subject for the analysis since it is one of the key concepts in chemistry classes of secondary level I. Additionally, many misconceptions about the particle model have been detected and studied (e.g., Fischler & Lichtfeldt 1997, Parchmann & Schmidt 2003). First of all, the idea of smallest building blocks contradicts the idea of a continuous structure of matter which is gained from everyday experiences. But even when the idea of a discrete structure has been accepted, the construction of adequate model understanding remains difficult. The most common misconceptions can be classified roughly into three groups[4] (see also Fischler & Lichtfeldt (1997, p. 5) and Mikelskis-Seifert (2002, p. 17)):

**Nature of the particles.** Macroscopic behavior and features are transferred to the particles. Common ideas are that the particles have a color, melt when heated, are motionless, or stop moving after a while.

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[4] For more detailed information about students' ideas about models see Chapter 4.

**Environment of the particles.** It is assumed that the space between the particles is filled with a continuous substance. Common ideas are that air fills the space between the particles or that water particles are embedded into water.

**Characteristics of models.** A naive-realistic view is taken. Common ideas are that there is a right model, that models are copies of reality or provable facts.

### 6.2.1 Method

Expository texts on the introduction of the particle model were investigated in the textbooks *Elemente Chemie I*[5] (text 1) and *Chemie heute SI*[6] (text 2). These two textbooks were selected since they were the most frequently used textbooks in the above mentioned teacher survey. An analysis of Mikelskis-Seifert (2002) had already shown that physics and chemistry textbooks contain phrases and pictures that may reinforce or trigger common misconceptions. This aspect was therefore not considered again in this study.

For the analysis, an instrument was employed which was developed by the AAAS in the Project 2061[7] for investigating curricular material. Following the criteria of the subcategory "Addressing commonly held ideas" the following three questions were investigated:

1. Does the text address common misconceptions about the particle model explicitly?
2. Does the text present phenomena which challenge common misconceptions? If so, is the observation that students are assumed to expect explicitly compared to the actual observation?
3. Does the text explicitly ask students to reflect on their own ideas or on common misconceptions?

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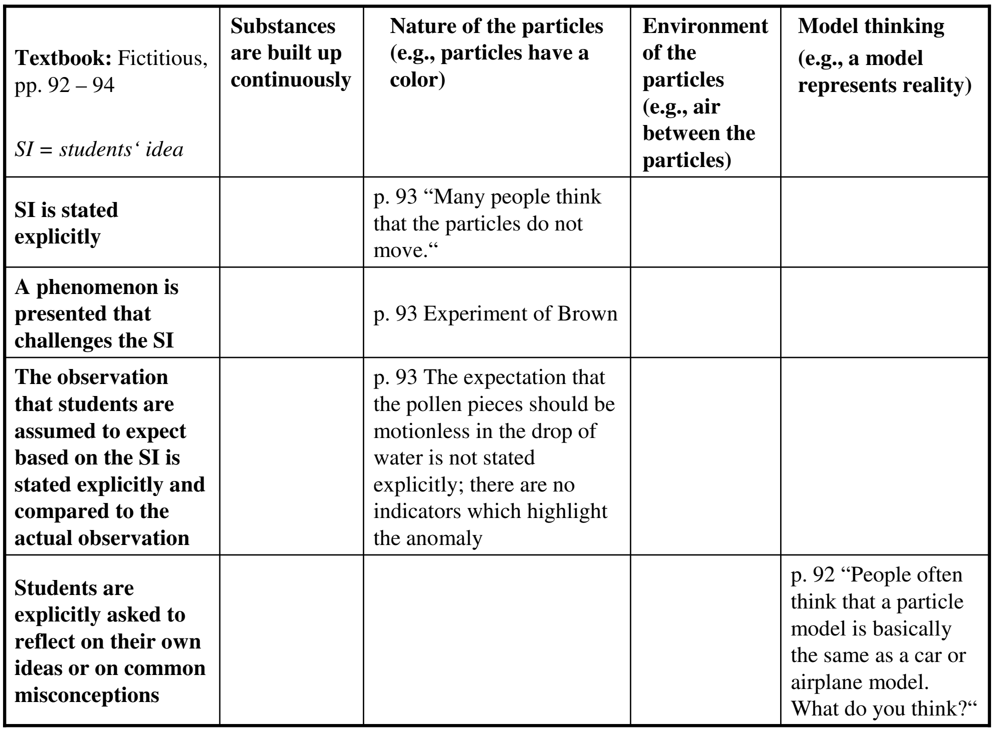
[5] Elemente Chemie I - Ausgabe A, Stuttgart 2001 (2. ed.)

[6] Chemie heute SI – Gesamtband, Hannover 2001

[7] http://www.project2061.org/publications/textbook/mgsci/report/crit-used.htm



| **Textbook:** Fictitious, pp. 92 – 94<br>*SI = students' idea* | **Substances are built up continuously** | **Nature of the particles (e.g., particles have a color)** | **Environment of the particles (e.g., air between the particles)** | **Model thinking (e.g., a model represents reality)** |
|---|---|---|---|---|
| **SI is stated explicitly** | | p. 93 "Many people think that the particles do not move." | | |
| **A phenomenon is presented that challenges the SI** | | p. 93 Experiment of Brown | | |
| **The observation that students are assumed to expect based on the SI is stated explicitly and compared to the actual observation** | | p. 93 The expectation that the pollen pieces should be motionless in the drop of water is not stated explicitly; there are no indicators which highlight the anomaly | | |
| **Students are explicitly asked to reflect on their own ideas or on common misconceptions** | | | | p. 92 "People often think that a particle model is basically the same as a car or airplane model. What do you think?" |

Figure 6.3: Category sheet for the textbook analysis. Fictitious entries are presented to visualize the analysis procedure.

The categories for the analysis were based on the groups of misconceptions described above and the three aforementioned research questions. Figure 6.3 shows the category sheet that was used for the analysis. Fictitious entries are presented in the matrix to visualize the analysis procedure.

### 6.2.2 Results

Does the text address common misconceptions about the particle model explicitly?

As the citations below show, the idea of a continuous structure of substances is addressed explicitly in one of the textbook texts. Additionally, alternative ideas about the nature of the particles and about characteristics of models are addressed explicitly. However, the misconceptions are partially addressed on a rather abstract level. For example, the text points out that an individual particle cannot exist in different states of matter but it gives no concrete examples for misconceptions such as “a sugar particle melts”.

*Idea of a continuous structure of matter*

- “When one looks at a liquid, it seems to be made up without gaps.” (“Betrachtet man einen flüssigen Stoff, so scheint er räumlich lückenlos aufgebaut zu sein.”, text 1, p. 50)

*Nature of the particles – Transfer of macroscopic features to the particles*

- “When models are visualized and represented, aspects may occur which must not be transferred to the smallest particles. Peas and mustard grains have a color, but our model makes no statement about a color of the smallest particles of a substance.” ( “Bei der Veranschaulichung und Darstellung von Modellen können Sachverhalte auftreten, die man nicht auf die kleinsten Teilchen übertragen darf. So haben Erbsen und Senfkörner eine Farbe, unser Modell sagt aber nichts über eine Farbe der kleinsten Teilchen eines Stoffes aus.”, text 1, p. 50).

- ”From the requirements of a particle model so far one can conclude immediately that an individual particle of a substance cannot exist in different states of matter. A state of matter is always bound to a portion of a substance which is made up of a very large number of particles.” (“Aus den bisherigen Forderungen für ein Teilchenmodell folgt unmittelbar, dass ein einzelnes Teilchen eines Stoffes nicht in verschiedenen Aggregatzuständen vorkommen kann. Ein Aggregatzustand ist immer an eine Stoffportion, die aus einer sehr großen Zahl von Teilchen besteht, gebunden.”, text 1, p. 53)

*Characteristics of models – Models as copies of reality*

- “Therefore, we have to be aware that we can not represent the smallest particles in a realistic way. We can only develop ideas and simplified representations which are approaches to parts of reality ... Whether the different sizes of the spherical particles are the only way to explain this [the volume contraction] cannot be deduced from this experiment [model experiment with peas and mustard grains]." (Wir müssen uns deshalb bewusst sein, dass wir die kleinsten Teilchen nicht wirklichkeitsgetreu abbilden können, wir können nur Vorstellungen und vereinfachte Darstellungen, die Teile der Wirklichkeit angenähert wiedergeben, entwickeln ... Ob die unterschiedliche Größe der Kugelteilchen die einzige Erklärungsmöglichkeit hierfür [die Volumenverringerung] ist, lässt sich aus diesem Versuch [Modellversuch mit Erbsen und Senfkörnern] nicht ableiten.", text 1, p. 50)

The idea that *there is a continuous substance between the particles* is addressed in both textbook texts, although only in an indirect way.

- "Even when the smallest particles are lying closely side by side, there is empty space between them, i.e., there is nothing between the particles." ("Selbst wenn die kleinsten Teilchen dicht nebeneinander liegen und sich berühren, tritt *zwischen* ihnen *leerer Raum* auf, das heißt, dass zwischen den Teilchen nichts ist.", text 1, p. 50)
- "There is nothing between the particles except empty space." ("Zwischen den Teilchen ist dabei nichts als leerer Raum.", text 2, p. 28)

### Does the text present phenomena which challenge common misconceptions? If so, is the observation that students are assumed to expect explicitly compared to the actual observation?

Both textbook texts present phenomena that have the potential to evoke a cognitive conflict in students. In order to challenge the idea of a continuous structure of matter, the volume contraction of a water/alcohol mixture is used. For questioning the idea of motionless particles, the experiment of Brown as well as the phenomenon of spontaneous mixing substances is presented.

The observation that students are assumed to expect is addressed explicitly in only one of the cases:

- "When one adds 50 ml of alcohol to 50 ml of water and shakes, one makes the surprising observation that the volume of the mixture is not 100 ml but only 96 ml. One would actually expect that the volumes add up when poured together, the same way as it happens when alcohol is poured to alcohol or water to water." ("Gibt man 50 ml Alkohol zu 50 ml Wasser und schüttelt, macht man die erstaunliche Beobachtung, dass das Volumen des Gemisches nicht 100 ml, sondern nur 96 ml beträgt. Eigentlich erwartet man, dass sich die Volumina beim Zusammengießen addieren, wie dies beim Zusammengießen von Alkohol und Alkohol oder Wasser und Wasser auch geschieht.", text 1, p. 50)

The other cases do not address the expected observation explicitly. However, there are mostly indicators for highlighting the anomaly:

- "When alcohol is mixed with water one makes a **surprising** observation: 50 ml of alcohol and 50 ml of water **only** yield 97 ml of solution. This volume **reduction** can be explained by..." ("Werden Alkohol und Wasser gemischt, so macht man eine **überraschende** Beobachtung: Aus 50 ml Alkohol und 50 ml Wasser entstehen **nur** 97 ml Lösung. Diese Volumen**verringerung** lässt sich erklären, ...", text 2, p. 23, bold type added by the author of this thesis)

- "When one holds a iodine crystal into alcohol, brown schlieren develop which sink to the bottom. After a while, the brown solution disperses through the whole liquid – **without stirring**." ("Hält man einen Iod-Kristall in Alkohol, so entstehen braune Schlieren, die nach unten sinken. Nach einiger Zeit verteilt sich die braune Lösung in der gesamten Flüssigkeit - **auch ohne Umrühren**.", text 2, p. 23, bold type added by the author of this thesis)

- "However, bromine steam diffuses from the bottom of an insulated cylinder without air streams, **although its density is higher** than the density of the surrounding air." ("Allerdings breitet sich Bromdampf in einem geschlossenen Standzylinder ohne Luftströmung vom Boden her aus, **obwohl seine Dichte größer ist** als die der ihn umgebenden Luft.", text 1, p. 51, bold type added by the author of this thesis)

As discussed above, an anomaly which is clear from an expert's point of view is often not perceived that way by novices. It would therefore be interesting to investigate whether students are aware of the conflicts which are not addressed explicitly. In other words, to which extent do students contemplate the following questions: Which observation was made? Which observation would I have expected? Based on which assumptions would I have expected this observation? Is the actual observation consistent with my assumptions?

### Does the text explicitly ask students to reflect on their own ideas or on common misconceptions?

Students are not explicitly asked in the textbook texts to reflect on their own ideas or on common misconceptions. It seems urgent, though, to moderately integrate such prompts into textbook texts in order to support students in developing metaconceptual awareness. Such text elements not only motivate students to individually reflect on similarities and differences between their own and scientific ideas. They can also be used as anchors for metaconceptual discussions in the classroom.

## 6.3 Criteria for the integration of students' ideas

As mentioned before, one important goal of the textbook analysis was to identify a text that could serve as a basis for the development of a conceptual change text and as a control text in the study presented in Chapter 7. Text 1 was chosen for this purpose. In the following, a paragraph of the newly designed conceptual change text is presented and some of the design criteria are explained.

Table 6.1 shows a section of the newly developed conceptual change text on the introduction of the particle model. The idea of a continuous substance between the particles is discussed in this paragraph. The notion of air between the particles is addressed explicitly and there is a comprehensive explanation why the model assumes empty space between the particles. Students are further explicitly asked to think about their idea of the structure of matter in comparison to the scientific idea. While these text elements rather focus on cognitive variables, there are also

> **What is between the particles?** For a long time, scientists could not imagine that substances are built up of individual particles. Why was it so hard for them? Quite simple, they could not imagine that a vacuum exists. You certainly know vacuum-packed food or you have heard of vacuum pumps. They pump air out of a vessel so that a vacuum is created inside. Since the air has been pumped out, there is nothing left in the vessel, even no air. In everyday life, in contrast, we observe that there is air is between all objects. Thus, many of us have difficulties to imagine "nothing" or "empty space". Nevertheless, try to understand the following argument: Air is a substance. Thus, it is built up of many, individual particles. Is there air between these particles? No, because it is the individual particles that make up the substance air. This means, there is nothing between the particles, only empty space! This also applies to all other substances like, for example, copper: There is nothing between the particles. According to this, what is between water particles? How did you imagine this before?

Table 6.1: Addressing of students' ideas: A section of the conceptual change text on the introduction of the particle model.

text elements which are intended to address affective variables. The text points out that many people have difficulties with the idea of "nothing", and it tries to tie in with students' everyday life experiences.

The whole catalog of criteria and the results of the comparison between the conceptual change text and the traditional textbook text are presented in Chapter 7.

## 6.4 Summary and discussion

Addressing of students' ideas, particularly of those that are not consistent with the scientific view, is pivotal for learning with understanding. Conceptual change texts tie in with this basic principle by not only presenting the scientific perspective, but also by addressing and refuting common misconceptions. The integration of conceptual change texts into textbooks could thus be a possibility to inform teachers about common alternative ideas and to provide instructional suggestions how to work with such ideas. The first study presented in this chapter therefore investigated whether and how Gymnasium teachers use textbooks for the lesson planning for chemistry classes of secondary level I. Confirming the results of Daus et al. (2004), the study found that textbooks play an important role for the preparation of chemistry instruction. Almost all of the participating teachers stated to use textbooks for obtaining suggestions on content-specific aspects that may be included into a new teaching unit.

Designing textbook texts according to principles of conceptual change instruction is also important with regard to the main purpose of textbooks, i.e., being learning aids for students. The second study presented in this chapter thus investigated whether and how current textbook texts address common alternative ideas. The analysis was done for texts on the introduction of the particle model found in two popular textbooks. The textbooks selected for this study were the two mostly used textbooks among the teachers of the survey. The analysis revealed that misconceptions are addressed explicitly in only one of the texts, although partly on a rather abstract level. Both texts present phenomena which challenge common misconceptions. However, there is only one occasion where the observation which students are assumed to expect is stated explicitly. For the other cases, there are partly indicators which are intended to highlight the anomaly. Metaconceptual prompts urging students to reflect on their own ideas or on common misconceptions are missing in both textbook texts.

Besides gaining information about how current textbook texts adhere to principles of conceptual change instruction, the analysis also intended to determine a traditional textbook text that could be used as a basis for designing a conceptual change text on the introduction of the particle model, and that could also serve as a control text in the study presented in Chapter 7. The aforementioned textbook text that does address misconceptions explicitly was chosen for this purpose.

Overall, the analysis showed that textbook texts attempt to address common ideas of students but that they do not take principles of conceptual change instruction sufficiently into account. A more systematic integration of alternative ideas is needed, not only with regard to students who use textbooks as learning aids, but also with regard to teachers who use them for planning their teaching. We thus exemplified at the end of this chapter how criteria, which have proven to be useful for conceptual change processes, can be implemented into a chemistry expository text. In the following chapter, the development of the criteria and the evaluation of the conceptual change text are described in detail.

For future research it would be interesting to develop conceptual change texts on different subjects and to investigate whether these texts can influence lesson planning in a way that students' ideas play a more important role in the chemistry classroom. The question of how these texts can be integrated effectively into teaching also needs further investigation.

# 7

# Study 3 – A conceptual change text on the introduction of the particle model: Development and evaluation

## 7.1 Introduction

One important goal of this thesis is to present a suggestion of how conceptual change texts for chemistry teaching can be designed, i.e., texts which take common misconceptions into account, which support students both in becoming aware of their own ideas and in understanding the scientific perspective. Addressing of students' ideas is crucial for sustainable learning as well as for students' motivation in science classes as discussed in detail in Chapter 2.

For developing text design criteria, a multidimensional approach was chosen based on the results of all the preceding chapters. The development of the guidelines and the relationship between the study presented in this chapter and the other parts of the thesis is visualized in Figure 7.1 and outlined in the following.

We first intended to define framework criteria which can generally be used by textbook authors and teachers as guidelines for designing conceptual change texts. Design criteria were deduced both from the theoretical perspectives on conceptual change and text comprehensibility, and from the empirical results of these research areas presented in Chapter 2 and Chapter 3, respectively. We additionally wanted to define criteria which meet the actual patterns of text use in the chemistry classroom and which adhere to the needs of practicing chemistry

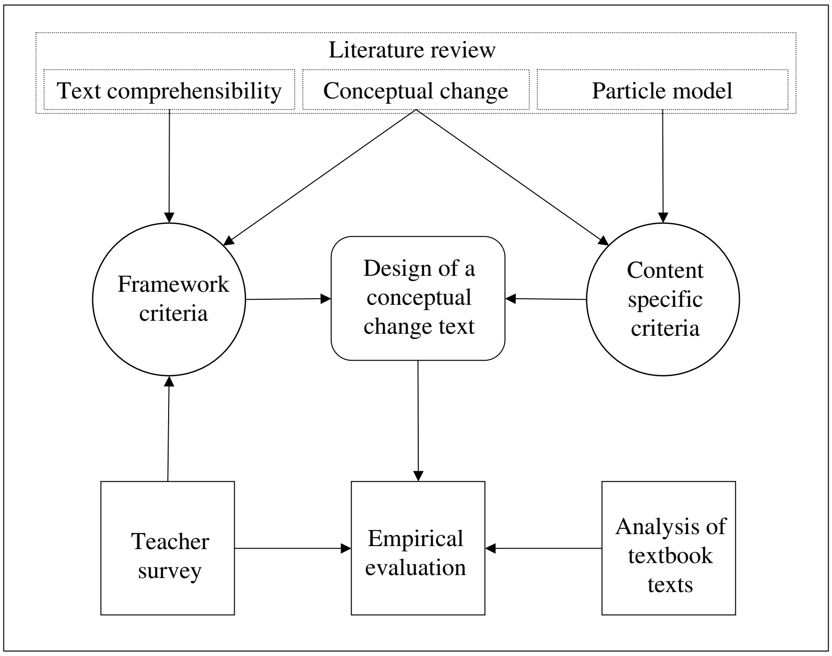


Figure 7.1: Workflow diagram of the development and the evaluation of a conceptual change text on the particle model.

teachers. The results of the teacher survey presented in Chapter 5 were therefore also incorporated. The development of the framework criteria is elaborated in Section 7.2.1.

Besides the composition of general framework criteria, we sought to design a specific expository chemistry text according to these criteria. The introduction of the particle model was chosen as topic for this purpose. The selection of this subject was based on three reasons. First, the particle model is one of the key concepts in chemistry. Second, a lot of misconceptions are known, they have been investigated intensively and reported frequently. Third, despite the vast amount of research on this topic and the plethora of instructional approaches, students still encounter profound learning difficulties (see Chapter 4). For writing a conceptual change text on the particle model, content-specific criteria were needed in addition to the framework criteria. Results from research on conceptual change and on instructional approaches to the particle model presented in Chapter 2 and Chapter 4, respectively, provided fruitful suggestions in this context. Specifically, theories of conceptual change were used to analyze the most common misconceptions about the particle model. Based on the results of this analysis, literature on instructional approaches was reviewed yielding content-specific criteria for the design of a conceptual change text on the introduction of the particle model. The development of the content-specific criteria is elaborated in Section 7.2.2.

Eventually, a conceptual change text was written according to the framework and content-specific criteria. For the overall macrostructure of the text and the selection of phenomena presented in the text, we followed the traditional textbook text "text 1" of the textbook analysis presented in Chapter 6. The textbook analysis had revealed that this text addresses a range of misconceptions explicitly. The respective textbook was additionally the most widely used textbook among the teachers of the survey presented in Chapter 5. The newly developed conceptual change text was evaluated and compared to the traditional textbook text "text 1" in an empirical study with 214 students from German Gymnasiums. On the one hand, we were interested whether the conceptual change text supported students in becoming aware of the differences between model-inconsistent and model-consistent ideas. On the other hand, since motivational factors play a crucial role in conceptual change (Pintrich et al. 1993), we wanted to know how students liked the text, whether they thought the text was comprehensible, and what they suggested for its improvement. Results of the study are presented in this chapter[1].

## 7.2 Development of criteria for a conceptual change text on the particle model

As outlined above, a multidimensional approach was chosen for defining criteria for the design of a conceptual change text on the introduction of the particle model (see Figure 7.1). We first looked for general criteria which might serve as a framework for the overall conception of conceptual change texts for chemistry teaching. We then elaborated content-specific criteria that are relevant for the introduction of the particle model.

### 7.2.1 Framework criteria for the design of the text

For composing general criteria we analyzed the findings from the survey of chemistry teachers on the use of texts (see Chapter 5 and Chapter 6) as well as the results of the literature reviews on text comprehensibility (see Chapter 3) and on conceptual change (see Chapter 2).

#### Criteria deduced from the result of the teacher survey

We intended to design a text which seizes suggestions made by practitioners and which matches the actual patterns of text use in the chemistry classroom. The results of the survey of chemistry teachers (see Chapter 5 and Chapter 6) were reviewed from this perspective.

The investigation how texts are used in chemistry teaching revealed revision to be the most important domain for the application of textual material. The teachers in the survey stated to hardly use texts actively in the classroom for

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[1] A selection of results of the study presented in this chapter has been presented at the NARST conference 2006 (Beerenwinkel & Gräsel 2006).

working on new topics. The design of the conceptual change text should thus adhere to the fact that the main function of texts consists in revision and consolidation, often at home. Thus, a student should be able to work through the conceptual change text individually.

The results of the investigation of what teachers want textbook texts to look like coincide with basic criteria of text comprehensibility. The texts should use a simple (but not too simple) language, focus on main ideas, show a clear external structure, and present ideas in a logical order. Suggestions for improvement referred to the integration of students' experiences and to a better support of knowledge construction. The following guidelines were deduced. To account for students' experiences, examples from students' everyday life should be provided and common ideas of students should be addressed. To give better support for knowledge construction, questions that prompt thinking should be integrated and learning goals should be provided at the beginning of the text.

The survey further demonstrated that the audience of textbooks are not only students but also chemistry instructors. The teachers in the survey stated that textbooks are important sources for their lesson planning, and nearly half of the participants stated to use explanations that are presented in the textbooks. This suggests that textbooks could serve as a medium between educational research and actual classroom teaching. When texts explicitly address common misconceptions, they concurrently inform teachers about alternative ideas and they also provide at least one didactic suggestion of how to deal with these ideas.

### Criteria deduced from prior research on text comprehensibility

The content of scientific texts is often very complex. Additional difficulties, which stem from linguistic or structural aspects should, therefore, be avoided. Theoretical perspectives on text comprehensibility and empirical research in this area have provided a plethora of guidelines which enhance the comprehensibility of texts, as elaborated in Chapter 3. In the following, a summary of guidelines is presented, which have been developed by inductive and deductive approaches for the design of expository texts in general and for chemistry and conceptual change texts in particular.

1. External structure
    - Write clear paragraphs.
    - Use precise headlines or marginalia.
    - Use an appropriate font size.
2. Simple language
    - Use short, clear sentences.
    - Use a moderate number of technical terms.
    - Provide explanations of technical terms in a straightforward manner using familiar notions.
3. Conciseness
    - Care for a moderate degree of information density.
    - Care for a moderate degree of redundancy.
    - Focus on main ideas, neglect unimportant information.
4. Logical structure
    - Adhere to the "Adressatenbezug" (each sentence contains at its beginning a part of the information presented in the preceding sentence).
    - Avoid a structure which requires many inferences.
    - Present different topics successively and continuously (continuity of the macrostructure).
5. Stimulations
    - Use stimulations only in combination with high structure and simple language.
    - Use a moderate degree of lively expressions.
    - Ask questions that prompt thinking.

6. Relevance indicators
    - Highlight important aspects (e.g., bold letters).
    - Direct the readers' attention to important aspects by asking explicitly to pay attention.
    - Provide summaries.
7. Addressing of prior knowledge
    - Tie in with students' prior knowledge (What do they already know? Which aspects should be reviewed?).
    - Address students' experiences from everyday life.

Regarding the special genre of conceptual change texts, the following structure is suggested:

1. Present naive ideas/misconceptions.
2. Demonstrate limitations of these ideas.
3. Present the scientific concept.
4. Highlight how the scientific concept addresses the limitations.

Conceptual change texts should additionally include text elements that focus on developing students' metaconceptual awareness. They should contrast the scientific view with students' ideas explicitly.

### Criteria deduced from prior research on conceptual change

The review of research on conceptual change in Chapter 2 brings together findings from instructional research and from cognitive science. Both domains provide fruitful suggestions for the design of conceptual change texts. The most important and fundamental result of this huge research field consists in the principle that students' ideas have to be addressed and taken into account seriously. However, it is not clear how misconceptions should be addressed. Vosniadou (1994) argues that it not sufficient to only address apparent misconceptions since their formation is based on specific underlying beliefs. Sustainable learning requires these beliefs to be addressed first. We follow this idea in Section 7.2.2.

The often used method of evoking a cognitive conflict has proven to be effective and, at the same time, problematic. In order to use cognitive conflict instruction effectively, different aspects have to be considered. First, the problem must be meaningful for students. Otherwise, they will hardly make the effort to restructure their knowledge base. Everyday problems are likely to be meaningful and interesting for students. Second, it has to be ensured that students possess all the knowledge that is important to understand the cognitive conflict. Since authors cannot evaluate each students' prior knowledge, they have to rely on the information given in the respective syllabus. However, authors might nevertheless review specific notions that are known to be crucial for understanding the conflict, or provide additional information or exercises. Third, students have to perceive the anomaly as credible data which is worth analyzing. Means to enhance the credibility of data presented in texts are descriptions of plain experiments which highlight the anomaly, multiple presentations of data, and the use of real-world data. Possibilities of reinterpretation should be minimized or discussed. Fourth, the new concept has to be presented in a plausible way and the author has to make clear why the scientific concept is more fruitful than the students' ideas – at least in certain contexts. Authors should provide different contexts and support students in building connections between context and the appropriate concept on the one hand, and between everyday and scientific concepts on the other hand. These connections are pivotal for the development of metaconceptual awareness which is key to conceptual change. Besides this metaview on different concepts, students should also develop a metaview on their own learning process. For scaffolding metacognitive thinking students can be provided with learning goals that help them to structure their learning activity, and they can be asked explicitly to review their learning process.

Table 7.1 summarizes the framework criteria for the design of conceptual change texts.

**Framework criteria**

- Design a text that supports revision and consolidation, and that can be used in individual work.
- Follow the structure:
    1. Present naive ideas/misconceptions.
    2. Demonstrate limitations of these ideas.
    3. Present the scientific concept.
    4. Highlight how the scientific concept addresses the limitations.
- If you demonstrate the limitations by providing anomalous data make sure
    - that the cognitive conflict is interesting for the students.
    - that the students possess all background knowledge that is necessary to understand the cognitive conflict.
    - to provide credible data.
    - to minimize and/or discuss possibilities of reinterpretation.
- Present the scientific concept in a student-appropriate and plausible way and make clear why it is more fruitful than the initial ideas of the students.
- Tie in with students' prior knowledge.
- Provide examples from students' everyday life.
- Address students' ideas from everyday life and common misconceptions that develop under instruction.
- Foster students' metaconceptual awareness by explicitly contrasting scientific ideas with alternative ideas.
- Foster students' metaconceptual awareness by providing different contexts.
- Foster students' metaconceptual awareness by asking questions that prompt thinking about their own concepts and about the relationship between their concepts and the scientific view.
- Foster students' metacognitive thinking by asking questions that prompt thinking about their learning process.
- Foster students' metacognitive thinking by providing learning goals.
- Create a clear structure of the text (e.g., write clear paragraphs).
- Present ideas in a logical order both on the microlevel and on the macrolevel (e.g., adhere to the “Adressatenbezug”).

Table 7.1: Framework criteria for the design of conceptual change texts

| **Framework criteria** |
|---|
| • Care for conciseness (e.g., focus on main ideas).<br>• Use relevance indicators (e.g., use expressions such as "It is important to understand, that ...").<br>• Use a simple language but avoid a flattening of language (e.g., use clear sentences, explain technical terms).<br>• Integrate a moderate degree of stimulations (e.g., direct speech). |

Table 7.1 (continued)

### 7.2.2 Content-specific criteria for the introduction of the particle model

For composing content-specific criteria, we employed the theoretical perspectives on conceptual change introduced in Section 2.3. The theories were used to analyze and explain the formation of the most common misconceptions about the particle model presented in Section 4.2.2. The analysis was conducted in order to reveal crucial aspects that might foster or hinder the development of misconceptions. The results of this investigation provided a lens through which we reviewed the literature on instructional suggestions on the introduction of the particle model. We looked for suggestions that could be implemented in an expository text, particularly one that is used for the purpose of consolidation in individual work.

#### Formation of misconceptions

As discussed in Section 2.3, there is no consensus about the theoretical perspective under which the formation of misconceptions or conceptual change in general should be viewed. Here, we do not intend to contribute to this discussion or to further develop any of the approaches. Instead, we try to use the available constructs for explaining the formation of common misconceptions about the particle model with the goal of deducing instructional implications. We do not see how any of the approaches can satisfactorily account for the range of misconceptions and problems connected with the particle model. But we think that some aspects can be applied fruitfully leading to promising suggestions for teaching practice.

In the following, we model the formation of misconceptions in a simplified way with the help of theories on conceptual change, especially with the theory of Vosniadou. The actual processes are, of course, much more complex and might differ from the suggested processes in many ways.

*Nature of the particles – Particles as small fractions of the substance.* In everyday life, children observe that a portion of a substance can be divided into smaller portions. For example, very early in their lives children observe that a bottle of milk can be poured into several glasses, each glass containing milk afterwards, that a bar of chocolate can be split into small parts, each fraction looking brown and tasting sweet. Later, they learn about tools like knifes or pipettes that help dividing when splitting by hand has come to its limits. Such observations lead to the belief that matter can be divided infinitely with each fraction having the same properties as the original portion of the substance, in other words, that matter is structured continuously. This view is challenged in science classes when children learn about the idea of discontinuity. It seems, however, that it is not the idea of discreteness itself which accounts for the learning problems in this field. Most students willingly accept the idea that matter is built up of smallest particles (e.g., Albanese & Vicentini 1997, Lichtfeldt et al. 1997). It is the modeling of these building blocks, the nature of the particles, which is hard to understand. Students often construct mental models of the structure of matter which indicate a discrete view, but which are nevertheless inconsistent with the scientific view. For example, copper particles are imagined as small, tiny, red, and shiny pieces. This suggests that the information of finite divisibility has been interpreted in such a way that the possibility to divide matter just stops at some point of time, for what reason soever. The particles are viewed as small, tiny portions of the substance that cannot be split any further. In other words, the assumption that any part of a substance has the same properties as the bulk substance has not been given up. In terms of Vosniadou (1994) we may say that the students have succeeded in integrating the idea of discreteness without giving up the assumption of property preservation by constructing a synthetic model.

*Nature of the particles – Transfer of macroscopic features/behavior.* There are also students who actually agree that the particles do not have all the properties of the bulk substance, but who nevertheless attribute macroscopic features or behavior to the particles. For example, they think that the particles have a temperature, color, or that they stop moving after a while. These misconceptions can also be seen as synthetic models which are formed because inappropriate assumptions are applied to the particles. This may be explained as follows. The introduction of the particle model is the first time that students encounter scientific modeling of submicroscopic entities. The submicroscopic world presents an unfamiliar context to them with which they have no experience yet. Analogical reasoning is a basic process for learning in such situations, i.e., features and relations from a similar, familiar context are transferred to the new one (Duit et al. 2001). In the case of the particle model, the model assumption that the particles have a specific mass and size and the use of visualization models like balls offer a link to a familiar, putative similar context, to the physical objects of the macroscopic world. This results in categorizing the particles as physical objects, and assumptions such as "inanimate objects do not move by themselves" are applied to them. Such assumptions about physical objects are built in earliest childhood (see Berk 2005, Bransford et al. 2000*e*, for a review), are deeply entrenched, and can be interpreted as presuppositions in terms of Vosniadou (1994).

Building a mental model of, e.g., the structure of copper under the presupposition of "inanimate objects do not move by themselves" results in the misconception that the copper particles do not move. A synthetic model has been formed by integrating the new information without reorganizing the existing knowledge structure. This suggests that the categorization of submicroscopic entities as macroscopic physical objects hinders the construction of appropriate mental models of the structure of matter. In the context of astronomy, Vosniadou & Skopeliti (2005) actually found that there is a relationship between the categorization of the earth as physical versus solar object and students' mental models about the shape of the earth. In terms of Chi et al.'s (1994) theory we may say that the concept of building blocks has to be shifted from the "matter" category into another category, one that comprises submicroscopic entities. The "matter" category is defined by attributes such as "is red", "is heavy", or "occupies space". One can make statements about the features of the objects in this category based on sensual perception. In contrast, submicroscopic entities are part of the hypothesis of the discontinuous structure of matter and cannot be perceived sensually.

Even though scientist usually do not doubt the existence of, e.g., atoms in their daily work, they are confined to the construction of mind models in order to make statements about the properties of submicroscopic entities. How sustainable the proposed model assumptions are is tested with the help of experiments. In contrast to the category of solar objects, students are seldom familiar with the modeling of submicroscopic entities from everyday life[2]. The category has thus to be "created" which is highly intricate since it challenges ontological and epistemological beliefs. For example, students are asked to accept the idea that there is a submicroscopic world that cannot be perceived sensually and that things are not as they appear. They are additionally asked to refrain from the belief that science provides an absolute "true" picture of the world. This may explain why students need time to fully understand the nature of statements about submicroscopic entities. It is unlikely that learning about one object is sufficient to understand the nature of the whole category.

*Environment of the particles.* Children experience from early childhood on that every space is filled with either solids, liquids, or gases, especially with air. The idea of building blocks comprises the idea of empty space, though. To avoid this conflict students may reinterpret the information of discreteness in that substances "have" building blocks which results in mental models such as water particles embedded in water. Another possibility is to assume air between the particles analogous to the ubiquity of air in everyday life (Fischler & Lichtfeldt 1997). From an expert's perspective this view seems inconsistent (What is between the particles of air?). However, students might have not thought about the structure of air and the space between the particles in one and the same context yet. Thus, the conflict stays hidden. On the other hand, students tend to assign a special status to air, i.e., they do not see air as a substance (Barke & Harsch 2001*a*).

*Model thinking.* Students often hold naive epistemological beliefs about the nature of science (e.g., Carey et al. 1989, Gilbert 1991). It can be assumed that the belief that science provides an absolute "true" picture of the world constrains

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[2] Although notions such as atoms or molecules and pictures of submicroscopic entities are abundant in the media, students are seldom systematically introduced to the idea of scientific modeling.

the integration of information about scientific models. This may cause some of the main misconceptions about models discussed in Section 4.1.2, e.g., that students often assume that models are copies of reality or provable facts. These assumptions can result in the belief that the particle model describes the real nature of the particles or that the particle model is a wrong model that is only taught to younger students. In older grades, the correct model which describes how the particles really are will be taught.

*Limits of the approaches.* While Vosniadou's (e.g., 1994), and to some extent also Chi's (e.g., 1994), approach could be used to explain the formation of common misconceptions about the particle model, they give no account for the observation that students have difficulties in applying the particle model consistently across various contexts. For example, Mikelskis-Seifert (2002) used a paper and pencil questionnaire for investigating ninth and tenth graders understanding of the particle concept. Results showed that the two scales which described the transfer of macroscopic features and behavior to the particles, respectively, showed only a weak, although significant, correlation ($r = 0.34$). Vosniadou et al. (2004) suggest that forced questions may give rise to inconsistent response patterns by inhibiting the construction of internal models which are based on the individual assumptions of the students. However, Nakhleh et al. (2005) conducted an interview study with open-ended questions, and they also found that students did not use a submicroscopic, macroscopic or mixed view consistently across different substances or tasks, but changed their level of argumentation. They concluded that "middle school students seem to be in a state of transition in their understanding of matter and that their understanding is very fragmented and localized" (Nakhleh et al. 2005, p. 609). It appears that students' ideas about the structure of matter, particularly with regard to the particle model, and the development of these ideas under instruction are not as systematic as described above, but diverse and complex. DiSessa et al.'s (2004) request for a focus on the issue of contextuality in the further development of theoretical approaches to conceptual change seems pivotal. Situations that seem identical for an expert may be regarded as completely different by a novice (diSessa et al. 2004). A closer consideration of the issue of context may thus be a good starting point to work on the problem of coherent versus fragmented knowledge. A "systematic enrichment of cognitive approaches [e.g., Vosniadou (1994), see Section 2.3.1] with situated elements [e.g., Halldén (1999), see Section 2.4.2]" ("systematische 'Anreicherung' kognitivistischer Ansätze mit situationistischen Elementen"), as Stark (2002, p. 33) suggests, appears promising to tackle this complex task.

### Instructional implications

*Nature of the particles – Particles as small fractions of the substance.* As argued above, children experience in everyday life that splitting a portion of a substance results in property preservation. In order to not reinforce the idea of particles having the properties of the bulk substance, the idea of discreteness of matter should not be introduced via the repeated division method (Fischler & Lichtfeldt 1997). Thus, instead of going from the substance to the particles (particles as the smallest parts of the substance) one should go from the particles to the substance (particles as building blocks of the substance) (Buck 1994*b*). Buck (1994*b*) suggests using the analogy of the relationship between a system and its elements in order to help students in understanding substance properties as collective properties. A system (e.g., book shelf) has different features than its elements (e.g., boards, screws). Similarly, a substance has different properties than its building blocks.

Another pillar in this context is the use and discussion of multiple representations of the particle model (Fischler & Lichtfeldt 1997, Treagust et al. 2000). For example, when only red balls are used for representing copper particles, students might be even pushed to the idea of particles as small fractions of the substance.

*Nature of the particles – Transfer of macroscopic features/behavior.* For supporting students in realizing that the particles do not belong into the same category as macroscopic physical objects, it seems important to explicitly separate and contrast the submicroscopic world, i.e., the world of models, from the macroscopic world, i.e., the world of experiences (Mikelskis-Seifert & Fischler 2003*b*). The differentness of the particles from the objects of everyday life should be discussed as well as the essential need of scientific models as media for making inferences about the submicroscopic world. In this context, Mikelskis-Seifert (2002,

p. 313) cautions against using the argument that models are only necessary due to the small size of the particles. She argues that the results of quantum physics suggest that it is not the size of the particles but rather their differentness which is problematic for understanding the submicroscopic world.

During the introductory chemistry course students spend a lot of time with identifying and describing substance properties. A review and clarification of what is actually understood by the notion of substance might strengthen the awareness that it is inappropriate to transfer substance properties such as color to submicroscopic entities. A working definition for the notion of substance is suggested by Eilks (2002, p. 9): "Substances are anything that can be touched or kept in a vessel." ("Stoffe sind alles, was man anfassen oder in einem Gefäß aufbewahren kann.")

*Environment of the particles.* The misconception that particles are embedded into the substance might be reinforced by visualizations showing, e.g., water particles in front of a blue background (Eilks 2003). Although this aspect is crucial for textbook design in general, it is not relevant for the conceptual change text in particular. Regarding text design, Fischler & Lichtfeldt (1997) emphasize the use of a precise language. Ambiguous expressions such as "particles that are in a substance" should be avoided since they suggest the existence of two different and independent things.

Barke & Harsch (2001*b*) refer to the reluctance of accepting the idea of "nothing" between the particles and describe how also ancient scientists as Aristoteles were unwilling to accept the notion of vacuum. The disbelief in empty room was one reason why the theory of Demokrit had been repulsed for such a long time. Barke & Harsch (2001*b*) elaborate the likeness of students' thinking and the ideas of scientists in the past and conclude that the historical development offers valuable suggestions for instruction in this context. They argue that students, similar to the scientists of past centuries, have first to become familiar with the notion of (macro)vacuum before they can really understand the idea of empty space between the particles. It is also suggested that teachers should address "historical misconceptions" for showing students that also well-known scientists had difficulties in accepting the idea of empty space.

Since a lot of students assume air between the particles of a substance, Fischler & Lichtfeldt (1997) point out the importance of explicitly discussing the structure of the substance of air.

*Model thinking.* Texts on the particle model should address the belief that sciences provides a “true” picture of the world by discussing the nature of scientific models on a metalevel, and common misconceptions (e.g., “wrong models”) should be explicitly addressed in this context. Metadiscussions about models are regarded as key to building model thinking (Grosslight et al. 1991, Mikelskis-Seifert & Fischler 2003*a*).

Table 7.2 summarizes the content-specific criteria for the design of the conceptual change text.

## 7.3 Research questions

The purpose of the study was to investigate two main research questions:

1. Does the conceptual change text support students in building appropriate ideas about the particle model? Since the conceptual change text addressed misconceptions explicitly and explained comprehensively why they are model-inconsistent, we expected the conceptual change text readers to show a higher increase towards model-appropriate answers than the traditional text readers.

2. What do students appreciate about the text and what do they suggest for its improvement? Since the conceptual change text was written according to principles of text comprehensibility and since it addressed common ideas of students, we expected the conceptual change text to be assessed better by the students than the traditional text.

**Content-specific criteria**

- Highlight that particles cannot be categorized as physical objects analogous to objects of the world of experiences/perception. Presuppositions such as “Objects do not move by themselves” do thus not apply to the submicroscopic world.
- Address the epistemological assumptions that things are what they appear and that science provides a “true” picture of the world.
- Care for a clear separation and contrast between the submicroscopic world (the world of models) and the macroscopic world (the world of experiences/perception).
- Discuss the nature of scientific models on a metalevel and address common misconceptions in this context (e.g., “wrong models”).
- Do not introduce the particle model via the repeated division of a portion of a substance but highlight particles as (first) building blocks of substances.
- Emphasize that substances have different properties than their building blocks (“collective properties”).
- Use various representations and visualizations of the particles.
- Make clear that the notion of substance does not refer to the particles. Features of substances such as color make no sense in connection with the particles.
- Do not argue that we have to model the particles because they are too small to see but discuss the differentness of the particles from the world we know from everyday life.
- Avoid ambiguous sentences such as “particles that are in a substance” but use a precise language that emphasizes the relation between particles and the bulk substance.
- Refer to the notion of vacuum in general before addressing the idea of empty space between the particles.
- Discuss the structure of the substance of air explicitly.

Table 7.2: Content-specific criteria for the design of a conceptual change text on the introduction of the particle model

## 7.4 Method

### 7.4.1 Participants

The conceptual change text was evaluated in an empirical study with six eighth grader and three seventh grader classes at the Gymnasium level at four different schools located in small cities in Germany. Two distinct grade levels were chosen due to differences between the federal states with regard to the beginning of chemistry instruction. Both the seventh graders in North Rhine-Westphalia and the eighth graders in Rhineland-Palatinate were in their first year of chemistry education. Students in both states had two chemistry lessons per week (45 minutes each), and the syllabi of the two states were highly similar in content. At the time of the study, all students were familiar with the particle model which is a main aspect in the introductory chemistry course in both states.

There were 215 students with valid questionnaires, i.e., pre- and post-test questionnaires could be matched and the group (traditional versus conceptual change text) was specified. One student stated to have read the traditional text, but her statement on what she liked about the text referred to a feature that was only present in the conceptual change text. This student was excluded from the analysis. The remaining 214 participants comprised 146 eighth graders and 68 seventh graders, 125 male and 89 female students. The mean age was 13 years and 8 months.

### 7.4.2 Design and procedure

After a pilot study with two classes, the conceptual change text was evaluated with the nine classes described above. The study was conducted in the last quarter of the school year 2004/05. The experiment took place in a regular classroom situation during two consecutive weeks. In the first week, students completed the pre-test (20 min.). The following week, the students were randomly assigned to read the conceptual change text (111 students) or the traditional textbook text (103 students). After 15 minutes, the texts were collected by the teacher, and the students were given the post-test (25 min.).

### 7.4.3 Instruments

#### Instructional material

Two text versions on the introduction of the particle model were used in the study: a traditional text (TT) and a conceptual change text (CT). Both text were written in German language. The conceptual change texts was designed for the experiment according to the criteria presented in Section 7.2 (see Figure B.1 for the original text). The traditional text was taken from a chemistry textbook for secondary level I (Eisner et al. 2001, pp. 50-51). This decision was based on the results of the survey of chemistry teachers presented in Chapter 5 and on the textbook analysis presented in Chapter 6. In the survey, most of the teachers stated to use the above-mentioned textbook for their teaching. The qualitative analysis additionally showed that the text from this textbook addressed a range of common misconceptions.

The macrostructure of the traditional textbook text and of the conceptual change text is presented in Table 7.3 and Table 7.4, respectively.

The traditional and the conceptual change text were similar in structure and content. The subject of both texts was the introduction of the particle model. Both texts presented a particle model that assumes particles of pure substances being equal in size and mass. This is sensible at this point of time since students are not familiar with the idea of ionic compounds yet. The assumption of attraction between the particles was not addressed in the texts. Both texts described models as means for explaining phenomena and neglected the aspect of generating hypotheses using models. With regard to the structure of the texts, both started with the presentation of anomalous data, introduced the scientific concept in the following, and explained afterwards different phenomena using the new concept. The conceptual change text included the same phenomena as the traditional text (mixing of water and alcohol, dissolving salt in water), although fewer in number. The explanation of the dissolving process of common salt in water using the simple particle model is sometimes seen as problematic since it may contribute to the misconception of salts as molecular substances. To account for comparability, however, we adopted the example in the conceptual change text. On the other hand, using this example may not be problematic at all if later,

**Macrostructure of the traditional textbook text**

*Substances are built up of smallest particles.* (Main headline)

*No heading.* Description of the experiment of mixing water and alcohol.

*The idea of particles.* Presentation of the idea that water and alcohol are built up of smallest particles. Explanation of the experiment of mixing water and alcohol using the idea of particles.

*All substances are built up of smallest particles.* Presentation of a particle model (without the assumption of constant motion).

*The idea of spherical particles.* Introduction of the notion of model. Presentation of the idea to think of the particles as spheres. Addressing of the misconception that models are copies of reality. Addressing of the misconception that features of visualization models such as color can be transferred to the particles.

*Models and reality.* Extended description of the nature of scientific models.

*The motion of the smallest particles.* (Main headline)

*No heading.* Information that the particle model can be used to explain further phenomena and that it has to be expanded for this purpose.

*The constant motion of the smallest particles.* Presentation of the experiment of Brown. Expansion of the model by assuming constant motion. Explanation of the phenomenon using the particle model.

*No heading.* Presentation of the phenomena of perfume flavor spreading throughout the room and of air mixing with bromine. Introduction of the notion of diffusion. Explanation of the phenomena using the particle model.

*Dissolving and crystallizing.* Presentation of the phenomenon of salt dissolving in water and crystallizing by evaporation. Explanation of the phenomenon using the particle model.

*No heading; framed.* Summary of the statements of the particle model.

Table 7.3: Macrostructure of the traditional textbook text on the introduction of the particle model used in the study.

**Macrostructure of the conceptual change text**

*Substances are built up of smallest particles.* (Main headline)

*You learn in this text...* Presentation of learning goals.

*What you should know.* Presentation of a rough definition of the notion of substance (prior knowledge).

*A problem.* Description of the experiment of mixing water and alcohol.

*The limits of our perception.* Discussion about the limits of our perception. Introduction into the discreteness of the structure of matter. Introduction of the notions of building block, particle and model.

*How do we imagine the particles?* Presentation of a particle model.

*When do particle models help?* Information that the presented particle model can be used to explain specific phenomena.

*The mysterious volume reduction.* Explanation of the experiment of mixing water and alcohol using the particle model.

*The mysterious disappearance of salt.* Presentation of the phenomenon of salt dissolving in water. Addressing of the misconception that particles are small fragments of the substance. Explanation of the phenomenon using the particle model.

*No heading.* Prompt to remind that the particle model is only an idea that helps to explain phenomena.

*Do the particles have a color?* Addressing of the misconception that the particles have the same features as the bulk substance.

*What is between the particles?* Addressing of the misconception that air fills the space between the particles of a substance.

*Is there a "right" model?* Addressing of the misconception that a model is right or wrong.

*At the end.* Prompt to review each paragraph and to compare the main ideas presented in the text with one's own ideas.

Table 7.4: Macrostructure of the conceptual change text on the introduction of the particle model used in the study.

| **Traditional text and conceptual change text** |
|---|
| • Same content<br>• Similar macrostructure:<br>*Anomalous data⟶Scientific concept⟶Phenomena*<br>• Same type of phenomena<br>• Metadiscussions about models |

Table 7.5: Similarities between the traditional text and the conceptual change text.

| | **Traditional text** | **Conceptual change text** |
|---|---|---|
| **Misconceptions:** | few passages, addressed rather indirectly or abstractly | many passages, addressed explicitly and concretely |
| **Phenomena:** | many | few |
| **Length:** | 807 words | 1165 words |

Table 7.6: Differences between the traditional text and the conceptual change text.

when students have learned about the idea of ions, the teacher re-addresses the phenomenon to discuss the strengths and limits of the simple particle model. Another similarity was that both texts included metadiscussions about models. Table 7.5 summarizes the similarities between the conceptual change text and the traditional text.

There were also significant differences between the two text versions (see Table 7.6). The main difference between the conceptual change and the traditional text was the way in which misconceptions about the particle model were taken into account. Although the traditional text did address a range of alternative ideas (see Chapter 6), there were more and longer text passages on misconceptions in the conceptual change text. Whereas the traditional text addressed some misconceptions in a rather indirect or abstract way, the conceptual change text addressed misconceptions explicitly and concretely (see Table 7.7). The conceptual change text additionally provided comprehensive explanations *why* such ideas are regarded as misconceptions (see Table 6.1 in Section 6.3).

Due to the extensive explanations the conceptual change text differed from the traditional text in its length. It comprised 1165 words, whereas the traditional text was only 807 words long. Most studies on text design use revised texts that are longer than the texts used as comparison. The extension of 44% in this study falls within a moderate range (e.g., Apolin (2002): 10% - 54%, Diakidoy et al. (2002): 99%, McNamara et al. (1996): 20% - 98%, Mikkilä-Erdmann (2001): 35%). If one does not compare the number of words but the number of characters, the conceptual change text exceeds only by 36% the traditional text.

The early introduction of the particle model at the beginning of chemistry education raises the question of how deep the discussion about the epistemology of science should go. Building appropriate epistemological beliefs takes time, a plethora of examples, and is difficult even for older students (Mikelskis-Seifert & Fischler 2003*a*). When younger students learn about the particle model, they are introduced to the world of scientific modeling for the first time. Since it is already difficult for them to understand, work on, and distinguish between mind models and visualization models, it has to be questioned whether a third level should be discussed, the hypothesis of the existence of smallest building blocks of matter. When students enter chemistry instruction, they are very familiar with ideas such as DNA molecules, electrons, quarks, or nuclear fission. A study with German seventh graders showed that almost all of the students stated that objects are made up of particles prior to instruction (Lichtfeldt et al. 1997). The media and most people seldom question the existence of atoms or molecules but view them as truly existent particles which form the heart of modern science. This picture is also imparted by most scientists in the public. Thus, the first example of theory building in chemistry classes would challenge a deeply anchored belief of students. Since they have no experience with the process of knowledge acquisition in science yet, they may be overwhelmed and disencouraged by the putative uncertainty and arbitrariness of science. Thus, we think that it is necessary that the discussion of

| **Traditional text** | **Conceptual change text** |
|---|---|
| *Indirect versus explicit:* | |
| “Even when the smallest particles are lying closely side by side, there is empty space between them, i.e., there is nothing between the particles.” (“Selbst wenn die kleinsten Teilchen dicht nebeneinander liegen und sich berühren, tritt *zwischen* ihnen *leerer Raum* auf, das heißt, dass zwischen den Teilchen nichts ist.”) (Eisner et al. 2001, p. 50) | “What is between the particles? ... In everyday life ... we observe that there is air is between all objects. Thus, many of us have difficulties to imagine ’nothing’ or ’empty space’ ... Is there air between these particles? No, because ... (“Was ist zwischen den Teilchen? ... Im Alltag beobachten wir dagegen, dass zwischen allen Dingen Luft ist. Daher fällt es den meisten von uns schwer, sich ’Nichts’ oder einen ’leeren Raum’ vorzustellen ... Befindet sich zwischen diesen Teilchen Luft? Nein, denn ...”) |
| *Abstract versus concrete:* | |
| “When models are visualized and represented, aspects may occur which must not be transferred to the smallest particles. Peas and mustard grains have a color, but our model makes no statement about a color of the smallest particles of a substance.” (“Bei der Veranschaulichung und Darstellung von Modellen können Sachverhalte auftreten, die man nicht auf die kleinsten Teilchen übertragen darf. So haben Erbsen und Senfkörner eine Farbe, unser Modell sagt aber nichts über eine Farbe der kleinsten Teilchen eines Stoffes aus.”) (Eisner et al. 2001, p. 50) | “Are the particles colored? What do you think is the color of a copper particle? The substance copper is red and shiny. Thus, many people think that a copper particle is red and shiny. But beware! ... An individual particle has not the same features as the substance! It is important that you are aware that we cannot transfer observations that we make on objects of everyday life to the particles! ” (“Haben die Teilchen eine Farbe? Welche Farbe hat deiner Meinung nach ein Kupferteilchen? Der Stoff Kupfer ist rot und glänzend. Daher denken viele, dass ein Kupferteilchen rot und glänzend ist. Aber Achtung! ... Ein einzelnes Teilchen hat nicht die gleichen Eigenschaften wie der Stoff! Es ist wichtig, dass du dir klar machst, dass wir Beobachtungen, die wir mit Dingen im Alltag machen, nicht auf die Teilchen übertragen können!”) |

Table 7.7: Examples for the addressing of misconceptions in the traditional text and in the conceptual change text.

the hypothesis of the existence of smallest building blocks needs to be preceded by a teaching unit about the nature of science (e.g., Carey et al. 1989). Another possibility is that the discreteness is not challenged principally, but introduced as adequately confirmed scientific knowledge as Eilks et al. (2001) suggest. Later, when students have more experience with theory building and modeling in science, this fundamental hypothesis can and should be discussed thoroughly. Since the syllabi of introductory chemistry courses seldom suggest teaching units about the nature of science (e.g., *Lehrplanentwürfe – Lernbereich Naturwissenschaften 1997)*, and since a comprehensive discussion would have gone beyond the scope of an appropriate length of the text, we chose a more realistic, simplified perspective in that we did not discuss the hypothesis of discreteness, but focused on the modeling of the submicroscopic entities. However, regarding the development of textbooks and not only one individual text as it was designed for this study, we suggest including a discussion about the nature of science, and thus also about the hypothesis of building blocks. The traditional text changes its position on the state of reality of the particles. First, it is stated that the phenomenon of volume contraction can be explained when one assumes that matter is made up of smallest particles. Later, it is concluded that we need to model the particles since they are too small to be perceived individually.

To sum up, the content of the conceptual change and the traditional text was the introduction of the particle model. The structure of the two texts was similar. The traditional text presented more phenomena for the use of the particle model, whereas the conceptual change text addressed common misconceptions more extensively.

### Measurement of students' learning and of students' satisfaction with the text

For measuring conceptual change, 18 closed-ended items and two open-ended questions were used. The items were partly based on those developed by Mikelskis-Seifert (2002) and referred to common misconceptions about the particle model and model thinking in general. The two open-ended questions were developed by Parchmann & Schmidt (2003) and asked students to apply the particle model in an everyday context. The questions of the pre- and post-test were the same[3]. The post-test additionally included questions asking for students' assessment of the text.

The teacher of the pilot study asked the students whether there were any comprehension difficulties. Students uttered to have no problems in understanding the questionnaire. Below, the questions are described in detail.

**Assessment of the text (7 questions).** Two items asked students whether they think the text was comprehensible and pleasant to read, and three items referred to students' interest in reading the text. They were asked to assess whether the text was written in a interesting way, whether they enjoyed reading it, and whether the text arose interest to learn more about models in science. The five items were scored on a 4-point scale from "I do not agree" (1) to "I agree" (4)[4]. Additionally, two open-ended essay-type questions asked students for what they liked and disliked about the text.

**Model thinking in general (6 questions).** To examine students' model thinking we used six items on the nature of scientific models (e.g., "If we make observations that cannot be described with the particle model you know, a new model should be developed"). The items were scored on a dichotomous scale ("I agree" (1), "I do not agree" (0)[5]). Additionally, students stated their degree of certainty about their answer on a second dichotomous scale ("I am sure" (1), "I am not sure" (0)[6]).

**Particle model in particular (12 questions).** Eight items were used to investigate students' ideas about the nature of the particles (e.g., "An individual sulfur particle is yellow"). Four items focused on the idea of the environment of the particles (e.g., "There is nothing between the individual particles that build up a substance"). These items were scored like the items on model thinking in general.

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[3] Some items of the pre-test contained the phrase "the particle model you know". This phrase was replaced by "the particle model described in the text" on the post-test.

[4] "trifft nicht zu" (1) to "trifft zu" (4)

[5] "Ich stimme zu" (1), "Ich stimme nicht zu" (0)

[6] "Ich bin mir sicher" (1), "Ich bin mir nicht sicher" (0)

**Application in everyday contexts (2 questions).** For testing students' ability to use the particle model for explaining everyday phenomena, students were given two open-ended questions. They were asked to explain how tea is made from water and tea leaves, and how sugar dissolves in tea. The questions had been developed and tested in a study conducted by Parchmann & Schmidt (2003) and proven to provide fruitful information about the ideas of the participating students. However, a lot of the students had not applied the particle model but had only argued on the macroscopic level. As we were interested in students' understanding of the particle model, we explicitly asked them to use the model in their explanation.

### 7.4.4 Statistical and qualitative methods

#### Students' learning

The methods that were used to investigate the question whether the conceptual change text supports students in building appropriate ideas about the particle model are presented in the following.

Some of the 18 items on the particle model were recoded, so that "1" represented the model-consistent answer[7].

For estimating students' knowledge, a common technique is to count the number of correct answers. Such sum scores, however, do not consider *which* items have been answered correctly. Models of Item Response Theory (IRT), in contrast, take this aspect into account by estimating students' proficiencies based on the difficulty of the items they solved[8]. Some basic features of this approach are outlined below, following Hambleton et al. (1991) and Wilson (2005).

IRT models are based on the estimation of a difficulty parameter for each item, and a proficiency parameter for each student. These parameters are used to model

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[7] See Table 7.9 for the recoded items.

[8] There are various other benefits of IRT such as that the proficiency estimates are not dependent on the specific set of items, that the item difficulty estimates are not dependent on the specific sample of students, or that standard errors are estimated for all proficiency estimates (Hambleton et al. 1991).

the probability for a particular response to a particular item. The most popular model is the one parameter logistic model or Rasch model for dichotomous data:

$$P(X_i = 1|\theta, \xi_i) = \frac{e^{(\theta - \xi_i)}}{1 + e^{(\theta - \xi_i)}} \tag{7.1}$$

The Rasch model models the probability to answer item $i$ correctly (i.e., a response of “1”) as a logistic function of proficiency $\theta$ and item difficulty $\xi_i$. Since this function models how an examinee responds to a particular item, it is also called item characteristic or item response function. The graph of the item response function of item $i$ with parameter $\xi_i = 2$ is plotted in Figure 7.2. The curve shows that the higher the proficiency estimate, the higher the probability to give a correct answer to item $i$. If the student’s proficiency parameter $\theta$ equals the item parameter $\xi_i$, the probability to respond correctly is 0.5. This becomes clear when $\theta$ is set to $\xi_i$ in equation 7.1:

$$\begin{aligned} P(X_i = 1|\xi_i, \xi_i) &= \tfrac{e^{(\xi_i - \xi_i)}}{1+e^{(\xi_i - \xi_i)}} \\ &= \tfrac{e^0}{1+e^0} \\ &= \tfrac{1}{1+1} \\ &= 0.5 \end{aligned}$$

The Rasch model presented above has two basic restrictions. First, it is only appropriate for dichotomous data. Second, it is a unidimensional model, i.e., it is based on the assumption that students’ performance on the test items can be predicted by one latent trait or underlying ability. Extensions of the Rasch model have been developed to come up with these drawbacks and have been implemented in different software programs. For analyzing the data of the study presented here, the IRT software GradeMap was used which has been developed by the Berkeley Evaluation and Assessment Research Center of the University of California, Berkeley (Kennedy et al. 2005). GradeMap uses the Multidimensional Random Coefficients Multinomial Logit Model which is a multidimensional, polytomous extension of the Rasch model (Adams et al. 1997). The software can also be used to model dichotomous data that measures only one latent trait (Kennedy 2005). GradeMap estimates item parameters using marginal maximum likelihood techniques whereas proficiency parameters can be estimated in

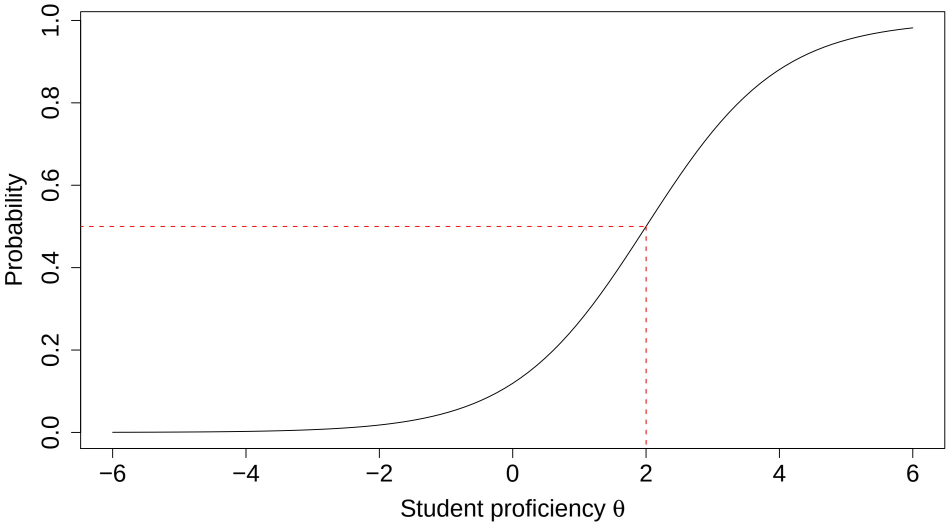

Figure 7.2: Item response function for item $i$ with difficulty $\xi_i = 2$. The probability for a student with a proficiency parameter of $\theta = 2$ to give a response of "1" is 0.5.

different ways. For the analysis, the pre-test data were used to estimate item difficulty parameters. Students' proficiency parameters were estimated for pre- and post-test using maximum likelihood estimation.

The questionnaire contained items referring to three theoretical constructs (model thinking in general, nature of the particles, environment of the particles). The assumed three-dimensionality was tested by comparing a three-dimensional Rasch model to a unidimensional one and by estimating the internal consistency of the subscales using Cronbach's $\alpha$. For evaluating model fit and the quality of the questionnaire, different methods were used following criteria presented in Wilson (2005). The evaluation was based on the pre-test data. To examine the appropriateness of the Rasch model for the data, item and respondent fit were investigated using the so-called infit mean square fit statistic. This approach compares how much the actual residuals (differences of observed and expected scores) vary in contrast to how much they are expected to vary if the data fits the model. A value of 1 indicates perfect model fit, values below 1 indicate less, and values greater than 1 more randomness than expected. Previous research has shown that infit mean square values between 0.75 and 1.33 indicate an appropriate model fit. For examining the reliability of the questionnaire we first analyzed the according Wright map, which is a graphical representation showing students' proficiency estimates and item difficulty estimates on a common scale. Second, the standard error of measurement of students' proficiency estimates was investigated. The question of whether the items are consistent with the instrument as a whole was evaluated by comparing the mean proficiency estimate of the "0" to the "1" scoring group for each item.

To check for the invariance of item parameters the item difficulties were estimated from the pre-test and post-test data separately. The correlation between the pre- and post-test estimates was calculated (Hambleton et al. 1991).

For testing on text design effects (CT: "conceptual change text" versus TT: "traditional text") an ANCOVA was performed with the pre-test as a covariate for the post-test proficiency. Since the proficiency estimates were given in logits, a common linear transformation was applied to get more convenient numbers. The proficiency estimates for the pre-test were transformed to make a mean of 500 and a standard deviation of 100. Post-test estimates and item difficulty estimates were transformed using the same equation (Hambleton et al. 1991). Gender and teacher were additional between-subjects factors in the ANCOVA. Gender was included because female students generally show a higher interest and competency in reading (Stanat & Kunter 2001). Since students' expertise in learning from scientific texts and their knowledge about and interest in the particle model may vary across teachers, this factor was also included. Within the scope of this study we were interested in a main effect of text design and in interaction effects between text design and gender or teacher, respectively.

For analyzing text effects on specific misconceptions, we analyzed descriptively the number of subjects who changed their answer from pre- to post-test for each item.

The two open-ended questions on everyday phenomena were analyzed qualitatively for misconceptions (see Mayring 2003). The analysis was based on the categories of common misconceptions about the particle model presented in Section 4.2.2. Following Parchmann & Schmidt (2003) two additional categories ("mixed level" and "non-material properties") were considered. Three more categories were defined inductively. We abstained from scoring the correctness of answers for three reasons. First, during the analysis it became apparent that in a lot of cases language problems were probably responsible for putatively model-inconsistent answers. Second, the goal of our investigation was to learn more about the actual ideas of the students. Thus, we did not ask the students to provide scientifically correct answers, but we encouraged them to openly describe their *own* ideas. Third, writing an explanation in one's own words and maybe additionally drawing a picture requires much more commitment than answering multiple choice questions. A study with ninth graders suggested that students have little motivation for writing texts in chemistry classes (Nieswandt 1997). We assume that motivational factors have also influenced the quality and comprehensiveness of the answers to the open-ended questions in this study. Students' answers varied from short statements such as "The different particles mix" to comprehensive explanations. Additionally, both the fact that students were not graded for the tests and that they had to work on the same test twice may have decreased their motivation. Fisher's exact test was used for testing for differences between conceptual change and traditional text readers regarding the number of answers in the different categories.

### Students' satisfaction

In order to investigate the question of what students appreciate about the text and what they suggest for its improvement quantitative and qualitative analysis methods were used.

T-tests were used to test for differences between the two experimental groups concerning their assessment of the text. The assessment items needed no recoding since "4" always represented the most positive ranking.

For getting suggestions of how to improve textbook texts from the students' perspective, an inductive qualitative content analysis was performed on the answers of the students to the questions what they liked and disliked about the text (see Mayring 2003).

## 7.5 Results

### 7.5.1 Does the conceptual change text support students in building appropriate ideas about the particle model?

#### Model fit and reliability

The comparison of the three-dimensional model (assuming three traits: competency about model thinking in general, nature of the particles, environment of the particles) to the unidimensional one (assuming one trait: competency about the particle model) showed that the more complex three-dimensional model did not fit the data better than the more simple unidimensional one. This observation was supported by the fact that the estimation of internal consistency reliability of the three theoretical subscales on the pre-test data yielded low indices. The unidimensional model was therefore chosen for the analysis and tested on item and respondent fit.

The infit mean square values of the item difficulty estimates were all within the range from 0.75 to 1.33 indicating good item fits. Figure 7.3 shows the infit mean square values of students' proficiency estimates. The scatterplot shows few values that are beyond the critical range from 0.75 to 1.33. Looking at the responses of the three students with the lowest infit mean square values revealed that they had the highest proficiency estimates. The difference between these students' proficiency estimates and the highest item difficulty estimate was so large that one would not expect those students to fail on an item. This explains the unexpectedly low degree of randomness. The responses of the three students with the highest infit mean square values also showed an interesting pattern. They all answered the three most difficult items model-consistently although the probability for this was low based on their proficiency estimates. Since we did not interview the students about their responses we have no indication for this unexpected response pattern. The infit mean square values of the vast majority of students was well-behaved, though, i.e., most students responded as expected. Overall, the analysis of item and respondent fit suggested the appropriateness of the unidimensional Rasch model.

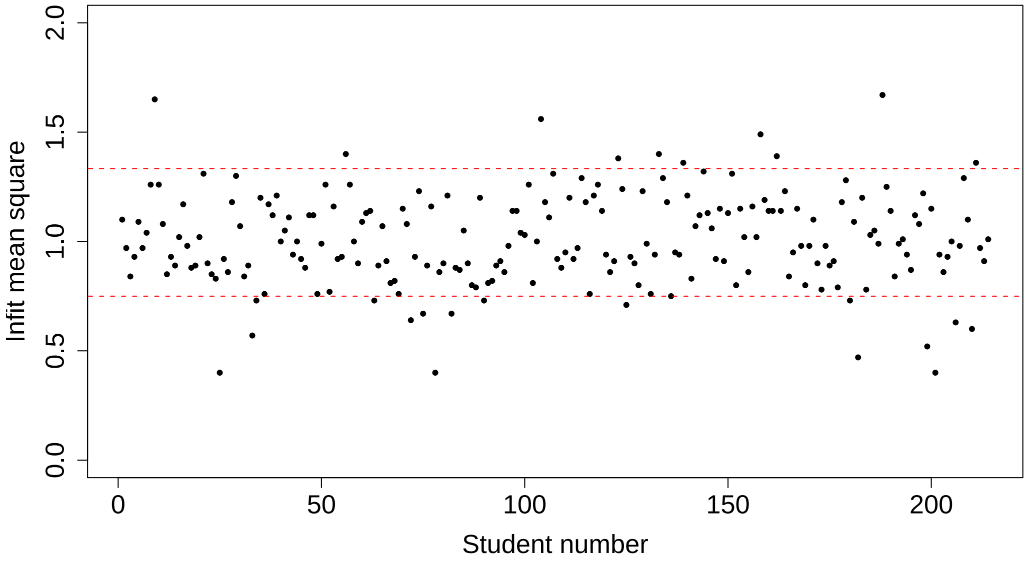

Figure 7.3: Infit mean square values of students' proficiency estimates.

The Wright map shown in Figure 7.4 visualizes the reliability of students' proficiency estimates. Wright maps make use of one of the benefits of IRT, the placement of items and respondents on a common scale. On the left-hand side of Figure 7.4, under "Proficiency Estimates", are noted the estimates of the student location. On the right hand side, under "Item Difficulty Estimates", are noted the estimates for the item location.

As can been seen in this figure, the items cover the most part of the student distribution. However, some students at the lower and upper end of the logit scale have no items near to their location which is a common problem. This means that the location of these students, in this case particularly of students at the top of the scale, is estimated with a higher error than the proficiency of students who are near to a lot of items (Wilson 2005). The low respondent fit of high achievement students discussed above reflects this problem.

Figure 7.5 shows the standard error of measurement of students' proficiency estimates for the pre-test data. Lowest errors are found for proficiency estimates around 0, which corresponds to the mean item difficulty. The sensitive part of

```
Log- Raw      Proficiency     Item Difficulty
it   Score    Estimate        Estimate
------------------------------------------------
   |                       |
   |18                   XX|
   |                       |
4  |                       |
   |                       |
   |                       |
   |                       |
   |                       |
   |                       |
   |                       |
3  |                      X|
   |                       |
   |                       |
   |                       |
   |                       |
   |16                   XX|
   |                       |
2  |                       |
   |15                  XXX|
   |                       |
   |                       |
   |                  XXXXX|
   |                       |env3   mod4
1  |13              XXXXXXX|nat5
   |12                   XX|
   |              XXXXXXXXX|env1
   |11                   XX|nat2   nat4
   |11     XXXXXXXXXXXXXXXX|
   |                     XX|
   |    XXXXXXXXXXXXXXXXXXX|
0  |        XXXXXXXXXXXXXXX|env4   nat3
   |8                    XX|nat7   mod6
   |               XXXXXXXX|
   |7                     X|nat1   mod5
   |7                XXXXXX|mod1   mod3
   |                  XXXXX|nat6   mod2
   |                       |nat8
-1 |5                  XXXX|env2
   |4                     X|
   |                       |
   |4                    XX|
   |                       |
   |3                     X|
   |                       |
-2 |                       |
   |                       |
   |                       |
   |                       |
------------------------------------------------
Each X represents 2 students, each row is 0,149 logits
```

Figure 7.4: Wright map for the pre-test data. Item labels are explained in Table 7.9.

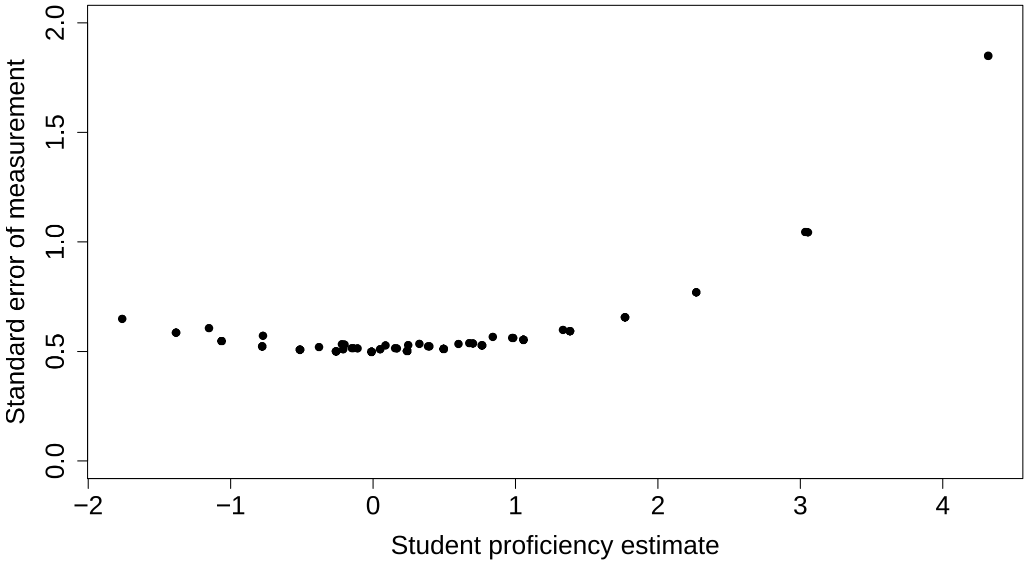

Figure 7.5: Standard error of measurement of students' proficiency estimates for the pre-test data.

the questionnaire is from approximately -1 to 1.5 logits and covers the majority of proficiency estimates. High errors occur for students with proficiency estimates over 2. The less reliable estimation of students on the upper end of the logit scale became more critical for the estimation of students' proficiency on the post-test, since the student distribution had shifted to more positive logits due to the learning effect.

Analysis of mean location showed that the items are consistent with the questionnaire as a whole. For each item the mean proficiency estimate of the "1" scoring group was higher than for the "0" scoring group.

The correlation between the item difficulty parameters estimated from the pre- and post-test data, respectively, yielded a coefficient of .75 ($p < .001$), which was acceptable but also indicated that, for future research, some of the items might be further developed.

To sum up, the data showed appropriate model fit and the items appeared to be consistent with the instrument as a whole. For improving the reliability of the questionnaire with regard to future studies, both the quantity and the range of items should be increased, especially towards the upper end of the difficulty scale.

### Text design effects (ANCOVA), mean values and degree of certainty

The assumption of homogeneity of regression slopes was tested before running the ANCOVA. No significant interactions between the covariate (pre-test proficiency) and the factor levels were found. The equality of regression slopes for both treatment conditions (CT/TT) showed that there was no interaction between prior knowledge and text design. The correlation between pre-test proficiency and gain (difference between post-test and pre-test proficiency) was negative. Low prior knowledge students thus benefited more from reading a text than high prior knowledge students, although the correlation was modest (CT: r = -.34, $p < .001$, TT: r = -.31, $p < .01$). However, one has to consider that the questionnaire fell short in measuring the proficiency of high knowledge students.

Table 7.8 shows the results of the ANCOVA with the pre-test result as a covariate for the post-test proficiency. Text design, teacher, and gender were included as between-subject factors. The model could account for 43% of variance (adjusted $R^2$). The covariate, pre-test proficiency, was significantly related to the post-test proficiency (F(1,190) = 56.49, $p < .001$). There was a significant main effect of text design after controlling for the effect of pre-test proficiency, favoring the conceptual change text (F(1,190) = 42.28, $p < .001$). There was no significant interaction between text design and any other independent variable. A main effect was found for the factor “teacher” combined with a disordinal interaction between “teacher” and “gender”. However, these effects were only weakly significant and of no further interest within the scope of the research questions investigated here. Remarkably, the variables “gender” and “teacher” had little influence on how students learned from reading the expository text.

Figure 7.6 presents a boxplot displaying the distribution of proficiency estimates of CT and TT readers for pre- and post-test. The boxes contain the middle 50% of the data (inter-quartile range). The upper edges of the boxes indicate the 75th and the lower edges the 25th percentiles of the data. The horizontal lines in

| Source | F | $p$-value |
|---|---|---|
| Pre-test | 56.49 | $2,2 \cdot 10^{-12}$ |
| Text | 42.28 | $6,8 \cdot 10^{-10}$ |
| Teacher | 2.50 | 0.032 |
| Gender | 0.21 | 0.651 |
| Text * Teacher | 0.86 | 0.510 |
| Text * Gender | 1.77 | 0.185 |
| Text * Gender * Teacher | 0.51 | 0.727 |
| Teacher * Gender | 2.59 | 0.027 |

Table 7.8: ANCOVA with the pre-test proficiency as a covariate for the post-test proficiency. Text design, teacher and gender were included as between-subject factors. Adjusted $R^2 = .43$.

the boxes indicate the median, and the dots the mean value. The lines extending from the boundaries of the boxes (whiskers) show the extent of most of the remainder of the data by extending to a maximum of 1.5 times of the inter-quartile range. Outliers are denoted by circles beyond the whiskers.

The outliers shown in Figure 7.6 mainly point to the fact that there were some students who answered all or almost all items model-consistently on the pre-test. The width of the CT post-test distribution and the difference between mean value and median is due to a peak of proficiency estimates around 800. CT and TT readers scored mean values of 502 and 498 on the pre-test, respectively. On the post-test, CT readers excelled TT readers with a mean value of 683 compared to a mean value of 551.

The certainty with which students gave model-consistent answers also increased from pre- to post-test. The average proportion of the “sure answers” of the model-consistent answers was 56% for TT and 55% for CT readers on the pre-test, which were not significantly different. On the post-test, the proportion of CT readers increased to 80%, which was significantly higher than the proportion of 69% of TT readers (t-test, $p < .001$).

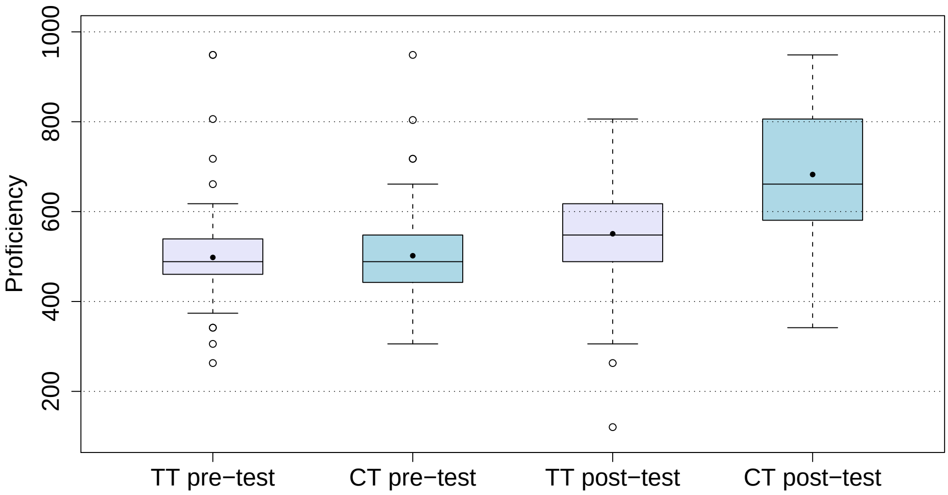

Figure 7.6: Distribution of proficiency estimates of traditional text and conceptual change text readers for pre- and post-test.

### Analysis of individual misconceptions

*Item difficulty.* Table 7.9 presents the ranking of the items according to their difficulty estimate (see Table A.7 for the original items).

The location of items about the environment of the particles (env) shows that it was easy for the students to deny the statement that liquid water fills the space between individual water particles. Items referring explicitly to the idea of emptiness or air between the particles were found to be difficult, though. Items about model thinking in general (mod) showed a lower to moderate degree of difficulty, with the exception of item mod4, which asked specifically whether the spheres of the particle model are similar to a concrete model like a globe. The easiest item about the nature of particles (nat) referred to the idea that particles are in constant motion. Items with more general statements such as “The particles have the same features as the substance they are building” showed a medium degree of difficulty. Items which gave specific instances for these general statements (e.g., “An individual sulfur particle is yellow.”) are found at the upper end of the difficulty scale.

| Item text | L | D |
|---|---|---|
| There is nothing between the particles that build up a substance. | env3 | 595 |
| Similar to a globe being a scaled down, simplified representation of the earth, the spheres in the particle model you know are a scaled up, simplified representation of how the particles look like in reality. (r) | mod4 | 594 |
| The individual particles building up frozen water have a lower temperature than those building up liquid water. (r) | nat5 | 578 |
| There is air between the individual particles that build up a substance. (r) | env1 | 546 |
| When water is heated to 30°C, the individual water particles have a temperature of 30°C. (r) | nat4 | 527 |
| An individual sulfur particle is yellow. (r) | nat2 | 524 |
| When a balloon is entirely filled with the gas helium, then there is air between the individual helium particles. (r) | env4 | 470 |
| The feature “shining” does not belong to an individual silver particle. | nat3 | 470 |
| The nature of the particles differs from anything we know from everyday life. | nat7 | 455 |
| The particle model you know is the only possibility how one can imagine the particles. (r) | mod6 | 443 |
| The particles have the same features as the substance they are building. (r) | nat1 | 411 |
| A particle model which is able to explain many observations describes how the particles look like in reality. (r) | mod5 | 408 |
| If we make observations that cannot be described with the particle model you know, a new model should be developed. | mod3 | 405 |
| Our idea about particles is an invention by humans intended to explain certain observations. | mod1 | 402 |
| The particles building up the substance sugar are tiny, white sugar pieces. (r) | nat6 | 388 |
| It is possible that the features of the particles differ from those we assume in the particle model you know. | mod2 | 378 |
| Since a rolling ball stops moving after a while, the particles will also stop moving sometime. (r) | nat8 | 367 |
| There is liquid water between individual water particles. (r) | env2 | 350 |

Table 7.9: Item ranking based on difficulty estimates. Item text, Label (L), Difficulty estimate (D). Higher values indicate higher difficulty. (r) indicates recoded items.

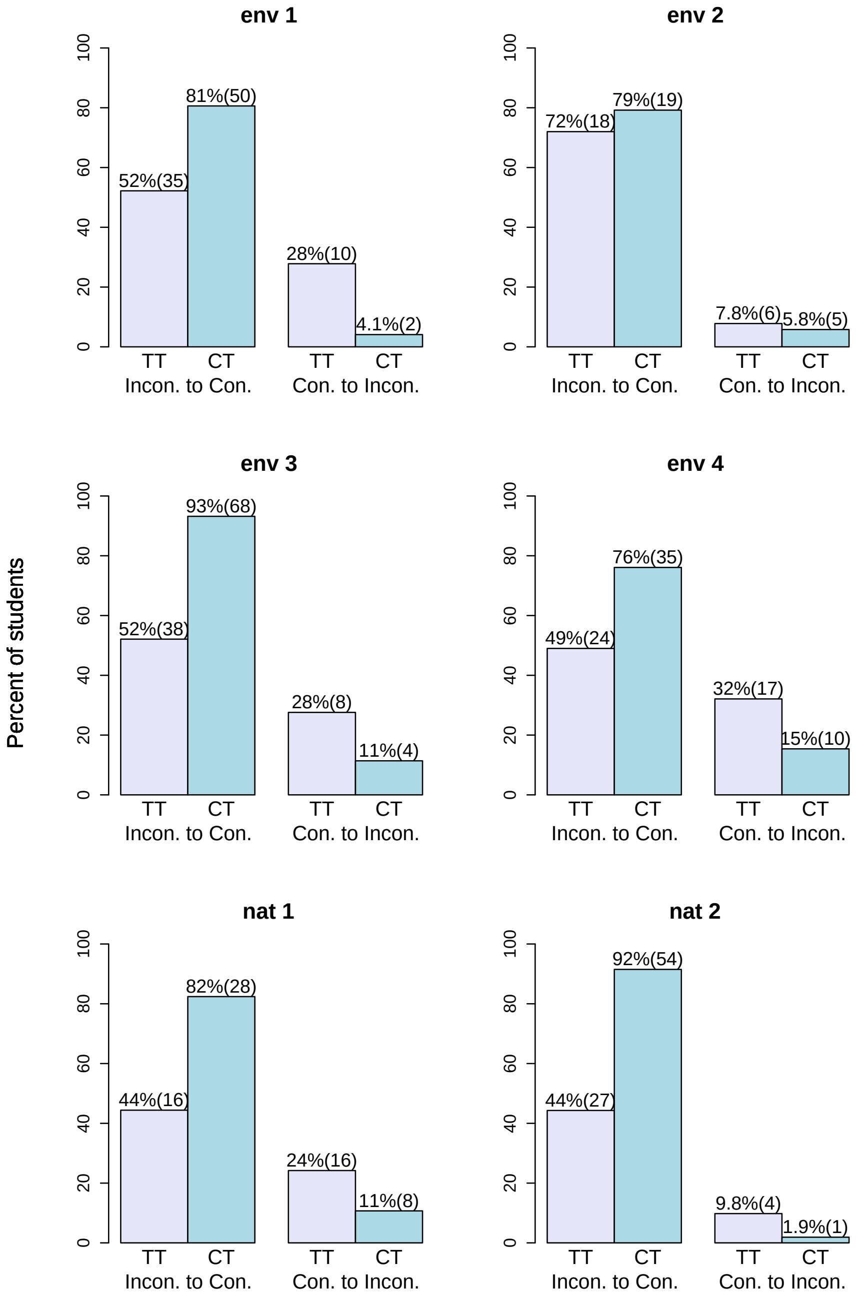

Figure 7.7: Percent of students who changed their answer from pre- to post-test. For example, 52% of the TT readers who gave a model-inconsistent answer (incon.) to item env1 on the pre-test gave a model-consistent (con.) answer on the post-test. Numbers in brackets denote absolute frequencies.

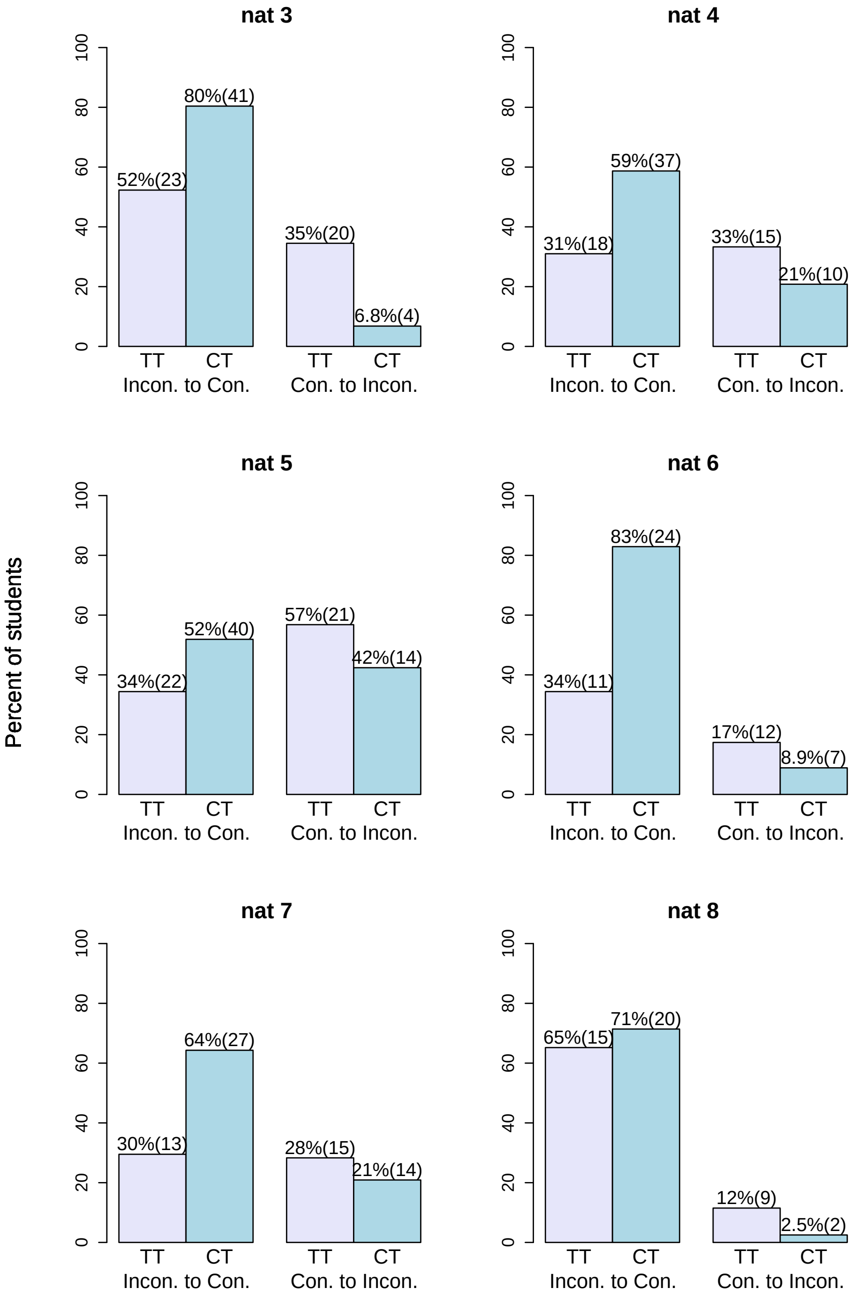

Figure 7.7 (continued)

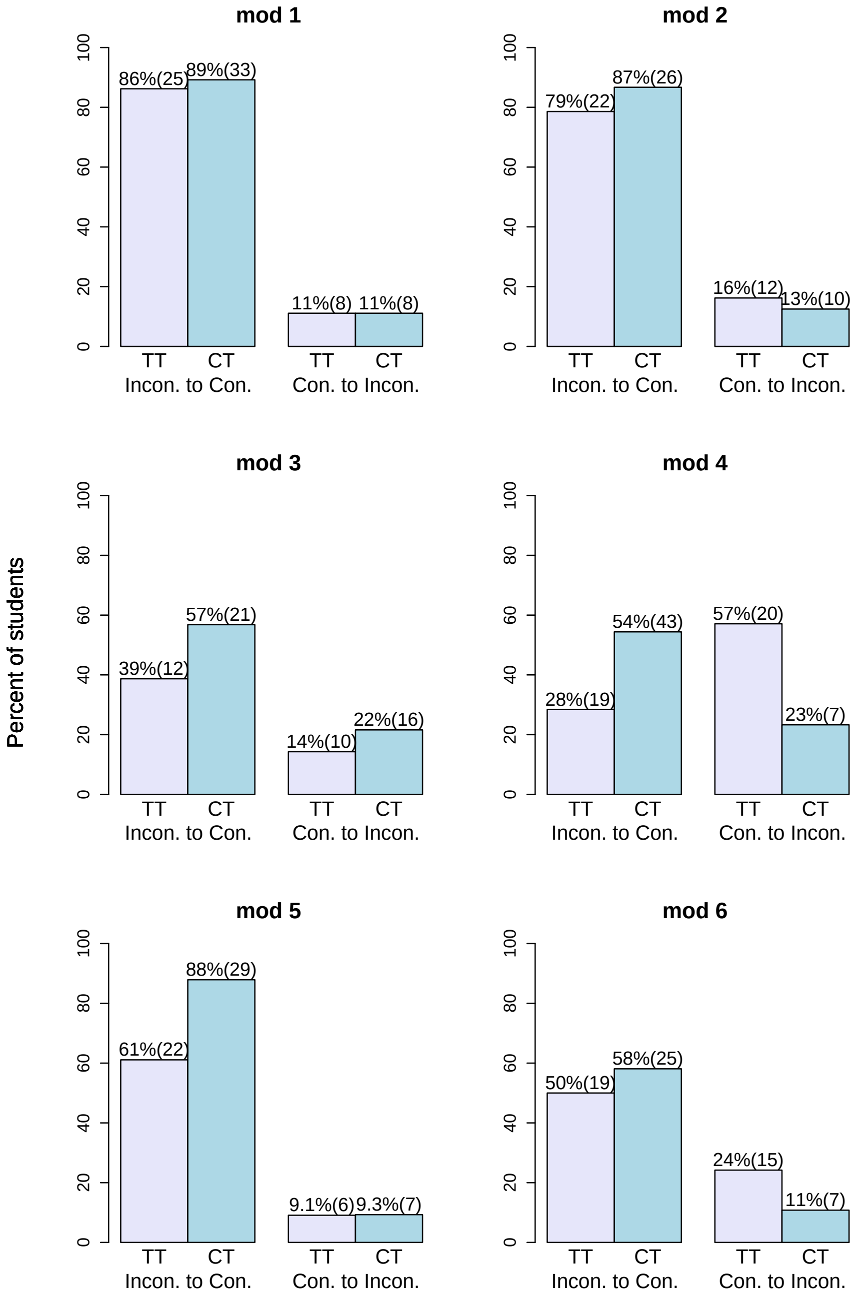

Figure 7.7 (continued)

*CT readers compared to TT readers.* Figure 7.7 shows the percentages of students who changed their answer from pre- to post-test. When we look at the group of CT and TT readers who gave a model-inconsistent answer on the pre-test, we can see that the proportion of students who gave a model-consistent answer on the post-test is higher among CT readers for all items. The group of CT and TT readers who gave a model-consistent answer on the pre-test shows an inverse pattern. The proportion of students who gave a model-inconsistent answer on the post-test is higher or equal for TT readers compared to CT readers for all items except item mod3. In the following we look at the three groups of items (environment of the particles, nature of the particles, model thinking) in detail.

*Environment of the particles.* The percentages of the four items on the environment of the particles show that the conceptual change text addressed this topic successfully. We find high rates of students who changed from model-inconsistent to model-consistent answers (76% (35)[9] - 93% (68)) and low rates for students who switched from model-consistent to model-inconsistent answers (4% (2) - 15% (10)). The traditional text shows similar rates only for item env2 which addressed the misconception of water particles embedded in liquid water. For the other items there are only moderate rates of change from model-inconsistent to model-consistent answers (49% (24) - 52% (38)) and higher proportions of students who switched from model-consistent to model-inconsistent answers (28% (8) - 32% (17)).

*The nature of the particles.* The items on the nature of the particles show a more heterogeneous picture. Regarding the conceptual change text, there are five items with high rates of change to model-consistent answers (71% (20) - 92% (54)) combined with low rates of change to model-inconsistent answers (2% (1) - 11% (8)). These items include one item about the general idea that the particles do not have the same features as the bulk substance (nat1), and four items with specific examples regarding the transfer of macroscopic features and behavior to the particles, e.g., "An individual sulfur particle is yellow" (nat2, nat3, nat6, nat8). Compared to the proportions of CT readers, the traditional text reaches similar rates only for item nat8 which refers to the constant motion of

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[9] The number in brackets denotes the absolute number of students.

the particles. The other four items show lower rates of change to model-consistent answers (34% (11) - 52% (23)) and higher percentages of students who switched to model-inconsistent answers (10% (4) - 35% (20)).

Item nat7 referred to the general idea that the nature of the particles differs from anything we know from everyday life, and item nat4 referred to the specific misconception that the particles have the same temperature as the substance they are building. For CT readers, these items showed moderate rates of change towards model-consistent answers (64% (27) and 59% (37), respectively), as well as to model-inconsistent answers (21% (14), 21% (10)). With regard to traditional text readers, lower rates of change were found towards model-consistent answers (30% (13), 31% (18)). The proportions of students who switched to a model-inconsistent answer were similar to those who changed to a model-consistent answer (28% (15), 33% (15)).

Item nat5, which asked students whether the individual particles building up frozen water have a lower temperature than those building up liquid water, indicates a clear deficit for both texts. Although the absolute number of CT readers (40) who changed to a model-consistent answer is much higher than the number of students who switched to a model-inconsistent answer (14), the rates of change on a percentage basis were similar (52% compared to 42%). Concerning TT readers, there were as many students who changed to a model-consistent answer (22) as students who switched to a model-inconsistent answer (21). On a percentage basis, the group which switched to a model-inconsistent answer (57%) even exceeded the group that switched to a model-consistent answer (34%).

*Model thinking.* Among the items on model thinking in general, there were three with high rates of change to model-consistent answers (CT: 87% (26) - 89% (33), TT: 61% (22) - 86% (25)) and low rates of change to model-inconsistent answers (CT: 9% (7) - 13% (10), TT: 9% (6) - 16% (12)). The items referred to the idea that models are constructs of human minds (mod1), that the particles may have different features than it is assumed in the model (mod2), and that models cannot tell the real nature of the particles (mod5).

The items which referred to the development of new models (mod3) and to the possibility of different appropriate models (mod6) show only moderate rates towards model-consistent answers (CT: 57% (21), 58% (25), TT: 39% (12), 50% (19)) and slightly higher rates towards model-inconsistent answers (CT: 22% (16), 11% (7), TT: 14% (10), 24% (15)).

Item mod4, which referred to the distinction between visualizations of mind models and concrete models of objects from the world of experiences, showed a similar pattern for CT readers. 54% (43) of the CT readers who gave a model-inconsistent answer on the pre-test changed to a model-consistent answer on the post-test, and 23% (7) of the students who gave a model-consistent answer on the pre-test changed to a model-inconsistent answer on the post-test. Readers of the traditional text showed a different picture. Only 28% (19) of the TT readers who gave a model-inconsistent answer on the pre-test changed to a model-consistent answer on the post-test, whereas 57% (20) of the students who gave a model-consistent answer on the pre-test changed to a model-inconsistent answer on the post-test.

To sum up, regarding switches from model-inconsistent to model-consistent responses or vice versa, the readers of the conceptual change text show a more favorable pattern than the readers of the traditional text. The results of the conceptual change text group indicate that the newly developed text addressed the issue of empty space between the particles well and that it also succeeded in taking the misconception of transferring macroscopic features to the particles into account. However, the text did not go into detail as to how the particle model is used to explain the concepts of temperature and heat, and the results show difficulties with items referring to this aspect. Students' answers to the items on model thinking further indicate that the conceptual change text presented the idea of models as constructs of mind effectively. They also suggest that the topics of model development and of differentiating between concrete models and visualizations of mind models need to be addressed more intensively.

### Analysis of the open-ended questions

The open-ended questions asked students to explain how tea is made from water and tea leaves (*Tea*), and how sugar dissolves in tea (*Sugar*, see Table A.8 for the original items). Subjects with no answer, with answers that did not refer to

| **Category** | **Example** | **Tea** | | **Sugar** | |
|---|---|---|---|---|---|
| | | *pre* | *post* | *pre* | *post* |
| Macroscopic level | “The herbs in the tea bag contain flavoring substances that dissolve in the hot water.” | 39% | 12% | 24% | 6% |
| Mixed level | “The tea goes into the empty spaces between the sugar particles. Thus, the particles disengage.” | 25% | 19% | 25% | 20% |
| Particle level | “Here again the smallest particles of sugar get disengaged and mix with those of the liquid.” | 36% | 69% | 51% | 74% |

Table 7.10: Categorization according to the levels the students referred to in their explanation. Examples for and frequencies of answers in the different categories.

the task, or with answers that only stated “the same as last time” were excluded from the analysis. The remaining data comprised 198 pre-test and 177 post-test answers for the tea question, and 189 pre-test and 179 post-test answers for the sugar question.

In order to get a first impression of the range of answers, we categorized them according to the levels the students referred to in their explanation. The category “Macroscopic level” comprised answers in which no substance was addressed on the particle level. Answers in which one substance was described on the macroscopic level and the other on the particle level were classified as “Mixed level”. Answers in which all substances were described on the particle level were categorized as “Particle level”. The quality of answers within the categories varied widely. Some answers contained no explanation, but only a description on the anticipated observation. Some answers were very short and incomplete, while others provided comprehensive explanations. The way the students modeled the substance tea was also different. Some referred generally to tea particles, while others modeled tea as being composed of particles of water, of flavoring, and of dye. Table 7.10 shows the percentages of answers within the different categories.

Although the students were explicitly asked to use the particle model, a high percentage did not refer to it on the pre-test. 39% and 24% stayed on the “Macroscopic level" for the tea and sugar task, respectively. These percentages decreased from pre- to post-test to 12% and 6%, respectively. The percentages on the "Mixed level" did not show large deviations between pre- and post-test (change from 25% to 19% and 20%, respectively). The vast majority of answers in this category described only the solid on the particle level which supports the assumption that the particulate structure of matter is rather accepted for solids than for liquids. Further investigations (e.g., interviews, drawings) might help to clarify whether students actually thought of the liquid as a continuum. The number of answers on the "Particle level" showed a large increase from 36% and 51% to 69% and 74%, respectively.

After this level based categorization, the answers were analyzed for specific misconceptions. Table 7.11 summarizes the results by showing category labels, examples, and the frequency of answers in percent for pre- and post-test[10].

We found most of the misconceptions described in literature (see Section 4.2.2), but not all. The potential of the tasks for revealing alternative ideas varied according to the type of misconception. For example, the idea of air between the particles occurred only in a few open-ended answers, although 60% of the students agreed to the statement that there is air between the particles on the pre-test. The problems seemed more adequate for detecting ideas on the nature of the particles. The category "Particles as macroscopic pieces" comprised answers which suggested that the students thought of the particles as small macroscopic pieces. In this context, difficulties associated with the notion of particle became apparent. The word particle is used in everyday language to refer to small pieces of a substance. In science, however, the notion of particle does not refer to macroscopic pieces but to submicroscopic entities. The conflicting use of the notion of particle in everyday and science language is problematic since the everyday meaning supports the idea of particles as small fractions having the bulk properties of the substance. The ambiguity of what students might have understood by the notion of particle imposes limits on the qualitative analysis. The classification into the different categories was based on fixed expressions found in the answers. For

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[10] The percentages do not sum up to 100% since a student's answer could cover multiple categories.

| Subcategories | Examples | Pre | Post | |
|---|---|---|---|---|
| **Nature of the particles: Particles as macroscopic pieces** | | | | |
| Particles are divided into smaller particles. | "Sugar is divided into many small particles which again divide into many other particles during dissolving..." | 14%<br>15% | 12%<br>12% | *Tea*<br>*Sugar* |
| Particles have macroscopic features. | "The hot water particles bump into the solid particles of the tea leaves ..." | | | |
| Particles show macroscopic behavior. | "They [the sugar particles] dissolve in the solvent." | | | |
| Particles contain other particles or substances. | "The flavoring substances are dissolved out of the individual particle by the hot water." | | | |
| Particles stop moving. | "While the leaves are drying, the particles stop moving." | | | |
| **Nature of the particles: Disappearance of particles** | | | | |
| Particles disappear. | "Eventually, the smallest particles dissolve completely. Now there are no more smallest particles in the tea." | 0%<br>1% | 1%<br>0% | *Tea*<br>*Sugar* |
| **Environment of the particles: There is air between the particles** | | | | |
| There is air between the particles. | "The smallest particles of tea go into the air filled gaps of sugar." | 0%<br>1% | 1%<br>2% | *Tea*<br>*Sugar* |
| **Mixed level. One substance is described on the macroscopic level, the other on the particle level** | | | | |
| The liquid substance is described on the macroscopic level. | "When adding water, the particles detach and swim in the water." | 25%<br>25% | 19%<br>20% | *Tea*<br>*Sugar* |
| The solid substance is described on the macroscopic level. | "The particles of the tea mix with the sugar so that the sugar gets dissolved." | | | |

Table 7.11: Categorization of answers to the open-ended application questions. Headlines in bold indicate the category name. Description of subcategories and examples are given below. Percentages of answers which were classified into the categories are presented separately for both questions (tea, sugar) and pre- and post-test, respectively.

| Subcategories | Examples | Pre | Post | |
|---|---|---|---|---|
| | **Non-material properties** | | | |
| Particles take on or give away properties. | “Since the solid cannot dissolve, it has its particles release smell.” | 6%<br>3% | 2%<br>1% | *Tea*<br>*Sugar* |
| Substances take on or give away properties. | “After a while, the tea leaves get soaked with water and release color and flavor.” | | | |
| | **The process is explained in that particles or substances react, combine or melt** | | | |
| Substances react/combine with each other. | “The flavoring substances are released by the water and react with water.” | 21%<br>19% | 13%<br>7% | *Tea*<br>*Sugar* |
| Particles combine with each other. | “The particles of the tea leaves combine with the particles of the water.” | | | |
| A substance reacts/combines with particles. | “The hot water combines with the flavor particles.” | | | |
| New particles are formed./Particles or substances melt into each other. | “This process results in the formation of sugared tea particles of one kind./The water and all particles of the leaves melt into each other.” | | | |
| Sugar melts/becomes liquid. | “The sugar is put into the tea. The sugar melts due to the heat in the tea.” | | | |
| | **The notion of flavor is used instead of flavoring substance** | | | |
| The notion of flavor (Aroma) is used instead of flavoring substance (Aromastoff). | “The warm water takes the flavor out of the leaves and mixes with it.” | 15%<br>1% | 8%<br>0% | *Tea*<br>*Sugar* |
| | **Transition** | | | |
| Inappropriate expressions are indicated by quotation marks. | “The ’heated’ water particles which move faster than the ’colder’ ones dissolve flavor particles out of the tea leaves.” | 4%<br>2% | 6%<br>6% | *Tea*<br>*Sugar* |
| The explanation contains notions that indicate the idea of liquids being built up discontinuously as well as expression suggesting a continuous view. | “The water particles detach individual sugar particles from the ’block’. Now the individual sugar particles swim around freely.” | | | |

Table 7.11 (continued)

example, when students used expressions such as “sugar particles decay further and further” or “the brown tea particles”, the answers were categorized as “Particle level” (or “Mixed level”) due to the use of the notion of particle. However, the students might have not thought of particles as building blocks of matter but of macroscopic sugar cubes and small pieces of tea leaves. Thus, the detection of some putative misconceptions about the nature of the particles might, in part, also be due to communication problems.

Besides misconceptions that directly corresponded to the particle model, other alternative ideas became apparent. Like Parchmann & Schmidt (2003), we also found some answers which suggested the concept of “non-material properties”, i.e., a phenomenon is explained by the transfer of properties without referring to a substance or particles. In this context, we added another category that covered answers in which the notion of flavor was used instead of flavoring substance. However, only answers that solely referred to flavor were grouped into this new category. Answers that referred to the transfer of other properties (e.g., color, taste) besides flavor were still categorized as “Non-material properties”. We decided to define a separate category since the notion of flavor (“Aroma”) is used ambiguously in everyday language. Although German distinguishes between flavor (“Aroma”) and flavoring substance (“Aromastoff”), the notion of flavor (“Aroma”) is often associated with a substance instead of a property. For example, it is common to say “adding lemon flavor to the dough” instead of “lemon flavoring”. Thus, when students used the notion of flavor, it was not clear whether they referred to a property or a substance. Some answers like the example in Table 7.11 suggested the latter use. This problem indicates a point of improvement with regard to the tea-question which used the ambiguous notion of flavor (“Take dried tea leaves and add hot water. You get a drink with a wonderful flavor and taste.”).

The second category that we added based on the analysis referred to answers that explained the making of (sweetened) tea in that particles or substances react, combine or melt. Here again, there were indications that deficiencies in the use of the scientific language might be responsible for putative misconceptions. In the introductory chemistry course the difference between mixtures and chemical compounds is introduced, and students learn about the notions of reacting and combining[11]. However, the answers suggested that the competency of precisely using the technical terms was still under development. For example, some students used the notions of combining and mixing in a synonymous way. The number of answers in this category showed the largest decrease from pre- to post-test.

The third category defined inductively was called “Transition”. The answers in this group suggested a phase of apparent transition from alternative to scientific ideas. The first subcategory included answers in which the students showed awareness of their deficient language skills. In the example presented in Table 7.11, for example, the use of quotation marks indicates that the student was aware that expressions such as “heated water particles” are inappropriate, but he or she did not know how to express him- or herself more appropriately. The second subcategory comprised answers which described the structure of liquids as particulate, but included also expressions which suggested a continuous view. Significant differences between conceptual change and traditional text readers regarding the number of answers in the different categories were not found[12].

Overall, the answers to the open-ended questions suggested that the students had problems in describing their ideas in written form. This impression was supported by the analysis of the drawings that some students made. There were a few cases where a drawing was the only reply to the question, i.e., no written explanation was given. These answers could only be categorized based on the pictorial representation. In most of the cases, however, the drawing was an addition to a written answer. Thus, we were able to first categorize the answer based on the written text, and then compare whether the drawing supported the categorization. For example, when a student wrote that water flows between the sugar particles, the answer was categorized as “Mixed level”. When the drawing showed the mixing of water and sugar particles, however, the classification was changed to “Particle level”.

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[11] The dissolving process is usually introduced as a physical process in the introductory chemistry course, and the interaction between, e.g., sugar molecules or ions with water molecules is discussed in later grades.

[12] Since 32 Fisher’s exact tests were calculated (8 categories, 2 tasks, 2 tests), the significance level was adjusted to 0.0015.

In the pre-test, there were 24 drawings, 21 of them with additional text. In 52% of the cases a correction to the prior categorization had to be made. In the post-test, there were 26 drawings, 21 of them with additional text. Here, in less than 10% of the cases the primary classifications needed be to changed. Thus, it seemed that after reading the texts, the students were able to better express their ideas in written form than before. The high number of corrections for the pre-test categorization additionally highlights the challenge of measuring students' ideas appropriately and the limitations of the qualitative analysis of the written answers.

## 7.5.2 What do students appreciate about the text and what do they suggest for its improvement?

### Analysis of the closed-ended items

Figure 7.8 shows the mean values of students' level of agreement to the five items which asked for an assessment of the traditional text and the conceptual change text, respectively (see Table A.9 for the original items).

Both groups assessed the comprehensibility of the text as good (CT: 3.7, TT: 3.5). No significant difference was found between the assessment of traditional and conceptual change text readers with regard to this aspect. In contrast, for the next three items, there were significant differences between the two texts. The students found that the conceptual change text was more pleasant to read (CT: 3.4, TT: 3.0, $p < .001$), that it was written in a more interesting way (CT: 3.0, TT: 2.6, $p < .01$), and that it was more enjoyable to read (CT: 2.7, TT: 2.2, $p < .001$). Regarding the last item, which asked whether the text rose interest in learning more about models in science, there was no significant difference between the two groups. Even the conceptual change text showed only an average level of agreement (CT: 2.4, TT: 2.2). This indicates an important point for future work. An interesting observation were the high standard deviations for the last three items. We assumed that some of the variance might be explained by gender and prior knowledge. Female students show a lower interest in chemistry instruction than male students (Kipker 2001) and also less competency in using

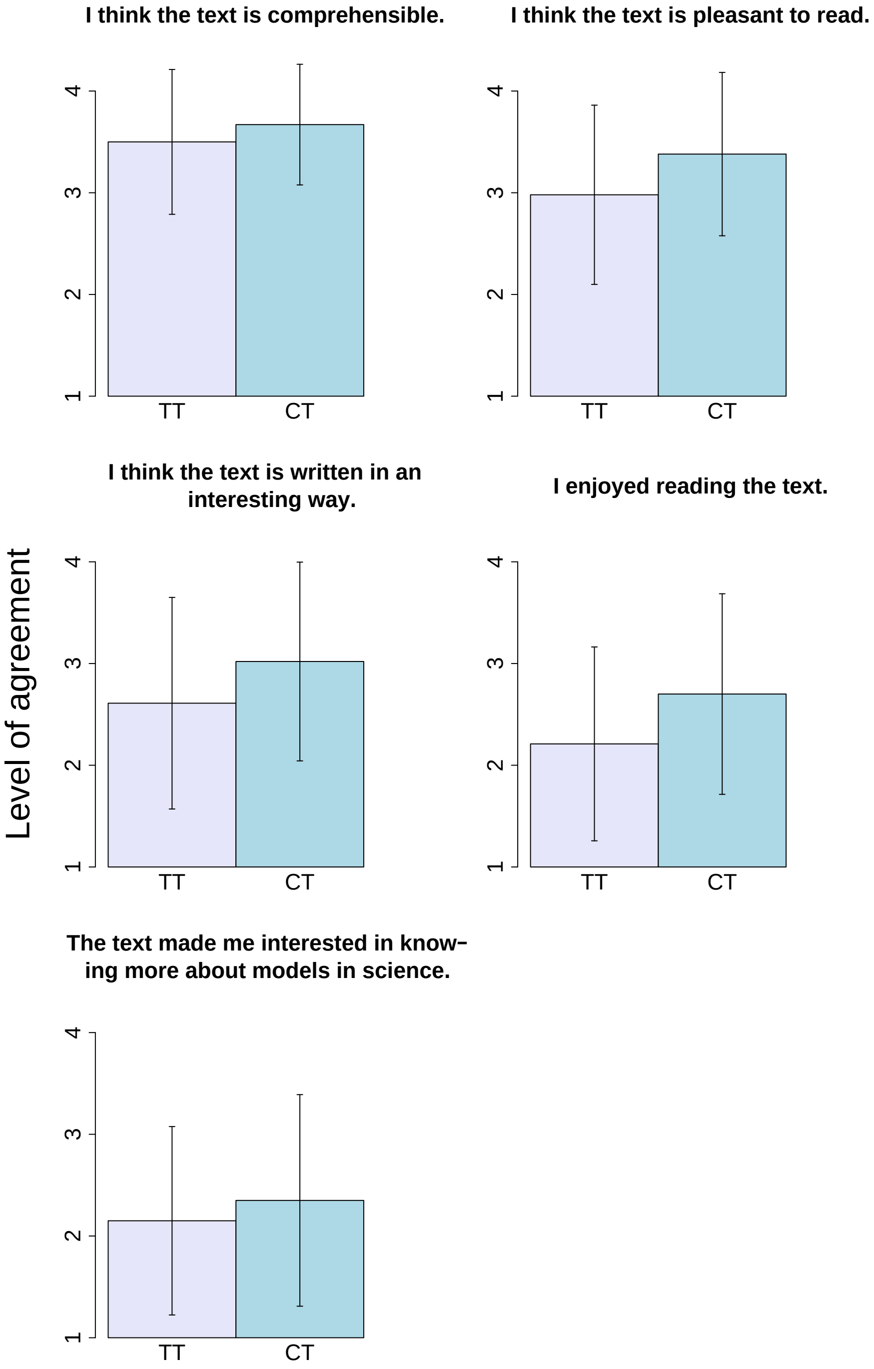

Figure 7.8: Mean values of students' level of agreement to the items which asked for an assessment of the text. Vertical lines indicate standard deviations.

mental models (Rost et al. 2005). We therefore supposed that a chemistry text on the particle model was rather interesting for male students. Prior knowledge might have also affected the assessment. Students with high prior knowledge might not find the text as interesting as low prior knowledge students, since they are already familiar with most of the material presented in the text.

The three items measuring whether the text was interesting for the students were combined in a scale (Cronbach's $\alpha = .78$), and a multiple regression was computed with gender and prior knowledge as independent variables. For the conceptual change text, a significant influence of gender was found, showing that female rather than male students assessed the text as interesting. For the traditional text, a significant influence of prior knowledge was found, showing that high rather than low prior knowledge students rated the text as interesting. Both models explained only a small portion of variance, though (CT: 5%, TT: 9%), but the tendencies were nevertheless surprising. We assume that there are more factors which influence whether a chemistry text raises students' interest and that the relationship between these factors is more complex. For example, female students usually show a higher general interest in reading than male students (Stanat & Kunter 2001), which might influence the assessment towards higher ratings. High prior knowledge students might be more interested in chemistry in general, which might also influence the assessment positively. Since the questionnaire did not measure these aspects, further research needs to address this issue.

### Analysis of the open-ended questions

For the analysis of the open ended questions "What did you like (dislike) about the text?" the following cases were excluded: students whose answer did not refer to the task, students who gave an answer that could not clearly be categorized as a positive or negative comment, students who did not answer to *both* questions. There were 205 students (CT 107, TT 98) with valid answers for the question of what they liked about the text and 204 students (CT 108, TT 96) for the question of what they disliked about the text.

*What students liked about the text*

Table 7.12 shows the most frequent positive aspects that were mentioned by the students. Only categories with more than 10% of CT or TT readers are represented[13].

When asked what they liked about the text, most of the students referred to the aspect of comprehensibility. More than two thirds of CT readers appreciated that the text was comprehensible compared to 45% of TT readers. The use of examples and comparisons was the second most frequently mentioned positive feature. A difference between the two groups was also found for this aspect, but not as pronounced as for the first one. The use of a pleasant, simple language as well as the structure and division into paragraphs were the next most often raised issues. The latter aspect was represented rather equally in both groups but the former one, the use of a pleasant language, was appreciated by more CT than TT readers. The following category, appropriate information content, comprised similar portions for both groups. The category of content-specific statements was represented more among TT readers, while the aspect of technical terms was raised more often by CT readers. These students appreciated that only few technical terms were used and that notions were explained in a simple way. Almost only TT readers commented positively on the highlighting of important facts and on the presence of a summary at the end of the text. There were also some students who either left the space for their answer blank (but answered to the question what they disliked about the text) or stated to like "nothing" about the text. This pattern was found more often for TT than for CT readers.

The remaining categories, which are not shown in Table 7.12, comprised less students, some of them containing only one statement: Interesting/not boring (CT 9% (10), TT 5% (5)), Use of headings (CT 7% (7), TT 8% (8)), Personal addressing (CT 7% (8), TT 0% (0)), Support of memorization (CT 5% (5), TT 4% (4)), Use of appropriate font (CT 0% (0), TT 3% (3)), Specification of learning goals (CT 2% (2), TT 0% (0)), Use of prompting questions (CT 1% (1), TT 0% (0)), Reference to prior knowledge (CT 1% (1), 0% (0)).

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[13] The percentages do not sum up to 100% since a student's answer could cover multiple categories.

| Category | Example | Percent of readers (Frequency) CT | TT |
|---|---|---|---|
| **Comprehensible** | "The text was easy to comprehend.", "The topic was explained well.", "I liked that notions were explained clearly." | **67.3%** (72) | **44.9%** (44) |
| **Use of examples and comparisons** | "I appreciated that the text contained so many examples. This way, one could imagine everything better.", "Examples from everyday life." | **29.0%** (31) | **20.4%** (20) |
| **Pleasant, simple language** | "It [the text] was written in a pleasant language, as if one student explains something to another student.", "It [the text] was written in a simple way.", "There were short and comprehensible sentences." | **30.8%** (33) | 5.1% (5) |
| **Structure, paragraphs** | "I liked that the text was well structured ... the text was well separated into different paragraphs." | **18.7%** (20) | **16.3%** (16) |
| **Concise, informative** | "It [the text] was not that long but detailed nevertheless.", "The text was very informative.", "The pieces of information were not cumulated, but spread evenly throughout the text." | **16.8%** (18) | **16.3%** (16) |
| **Content-specific statements** | "I liked that the text explained what one can explain using the particle model.", "The detailed description of the relationship between model and reality.", "That it described what I always wanted to know (e.g., What is between the particles? Air or vacuum?)" | **13.1%** (14) | **18.4%** (18) |
| **Few technical terms, comprehensible explanation of technical terms** | "There weren't so many technical terms, if so, they were explained in a simple way.", "There were only as many technical terms as necessary." | **14.0%** (15) | 6.1% (6) |
| **Highlighting of key facts** | "That key words were printed in bold type.", "Important notions were highlighted." | 1.9% (2) | **15.3%** (15) |
| **Summary at the end** | "I liked that the text summarized the most important facts at the end.", "The box at the end where everything was explained shortly." | 0.0% (0) | **11.2%** (11) |
| **Nothing** | "Nothing.", "That it [the text] wasn't even more longer.", left blank | 4.7% (5) | **10.2%** (10) |

Table 7.12: Categorization of students' answers to the question, "What did you like about the text?" Only categories with more than 10% of CT readers or TT readers are shown. Bold letters highlight percentages over 10%. "67.3% (72)" means that 72 CT readers (67.3% of categorized CT readers) appreciated the comprehensibility of the text.

*What students disliked about the text*

Table 7.13 shows the most frequent negative aspects that were mentioned by the students. Only categories with more than 10% of CT readers or TT readers are represented[14].

When students were asked what they disliked about the text, 49 students either left the space for their answer blank (but answered to the question what they liked about the text) or gave a statement like “nothing” or “everything ok”. There were more CT readers who had nothing to criticize about the text than TT readers. The most important aspect of criticism was the length and detailedness of the text. About a fourth of CT readers and a fifth of TT readers were not satisfied with this aspect. The next most frequently mentioned issues were that the text was too complicated and not very comprehensible and that it was not interesting. Both aspects were raised more often by TT readers. Language style and missing pictures were further points of criticism, again with a higher portion among students who had read the traditional text. The aspect of missing pictures is a good point since the traditional text does refer to pictures in its original form in the textbook. Since the study focused on the influence of written expository text and not on the effect of figures or pictures, the students were presented only with the text, neglecting the corresponding pictures. This condition was alike for both groups.

The remaining categories, which are not shown in Table 7.13, comprised less students: Content-specific statements (CT 6% (6), TT 4% (4)), General dislike of chemistry/the topic (CT 4% (4), TT 3% (3)), Too many technical terms/incomprehensible explanation of technical terms (CT 1% (1), TT 6% (6)), Bad structure (CT 4% (4), TT 4% (4)), Topic already well-known (CT 4% (4), TT 3% (3)), Too many repetitions (CT 4% (4), TT 3% (3)), Everything (CT 2% (2), TT 5% (5)), Too few/bad examples (CT 1% (1), TT 3% (3)), Too many comments in brackets (CT 4% (4), TT 0% (0)), Not detailed enough (CT 2% (2), TT 2% (2)), Too little highlighting of key facts (CT 0% (0), TT 3% (3)), No exemplary questions with solutions (CT 0% (0), TT 1% (1)).

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[14] The percentages do not sum up to 100% since a student’s answer could cover multiple categories.

| Category | Example | Percent of readers (Frequency) CT | TT |
|---|---|---|---|
| **Nothing** | "Nothing.", "Everything ok.", left blank | **30.1%** (33) | **16.7%** (16) |
| **Too long, too detailed** | "Too long.", "I didn't like that the text was so lengthy.", "Was written a bit too detailed. Could have been shorter.", "It was too much to remember everything." | **25.9%** (28) | **20.8%** (20) |
| **Not comprehensible, complicated** | "The text was partly hard to comprehend.", "One had to concentrate hard to follow.", "That it was written in such a complicated way.", "Everything was paraphrased a bit too widely." | **12.0%** (13) | **18.8%** (18) |
| **Not interesting, boring** | "It [the text] was boring and not very interesting.", "That it [the text] wasn't written in an appealing and interesting way and that it only contained facts and experiments." | 6.5% (7) | **17.7%** (17) |
| **Unpleasant language** | "The text was written too much in a matter of fact way.", "Sometimes too complicated sentences.", "Childish explanations." | 7.4% (8) | **11.5%** (11) |
| **Missing pictures** | "Unfortunately no pictures.", "There were no pictures which made the text a trifle harder to understand." | 2.8% (3) | **11.5%** (11) |

Table 7.13: Categorization of students' answers to the question, "What did you dislike about the text?" Only categories with more than 10% of CT readers or TT readers are shown. Bold letters highlight percentages over 10%. "30.1% (33)" means that 33 CT readers (30.1% of categorized CT readers) had nothing to criticize about the text.

## 7.6 Summary and discussion

A multidimensional approach was used for developing criteria for designing conceptual change texts for chemistry teaching. A text on the introduction of the particle model was designed according to the guidelines and evaluated in an empirical study. A traditional textbook text was used for comparison. Before we turn to the discussion of the results of the two main research questions of the study, some conclusions from the assessment of students' knowledge are drawn and difficulties related to the evaluation of the ideas of students are discussed.

### Conclusions from the assessment of students' knowledge

The assessment of students' prior knowledge highlighted the challenge of building appropriate ideas about the particle model. Although all students had been taught the particle model and had worked on it and its applications before the experiment was conducted, model-inconsistent ideas became apparent in the study. For example, students showed difficulties with the idea of emptiness between the particles and with the notion of temperature in connection with the particle model. The spheres of the model were rather seen as a concrete model than as a visualization of a mind model. For explaining everyday phenomena a lot of students argued on the macroscopic level, although they were explicitly asked to use the particle model.

Students' answers further showed uncertainty and, from a scientific point of view, inconsistencies resulting in low reliability coefficients. For example, 36% of the students stated that the particles do not have the bulk features of the substance, but they attributed the color yellow to individual sulfur particles. Inconsistent answering patterns have often been observed in conceptual change research. Driver et al. (1985*a*, p. 3) concluded that, "... the same child may have different conceptions of a particular type of phenomenon, sometimes using different arguments leading to opposite predictions in situations which are equivalent from a scientist's point of view, and even switching from one sort of explanation to another for the same phenomenon." One might assume that the closed-ended questions were the reason for the observed lack of consistency as Vosniadou et al.

(2004) suggest. They argue that it may be easier for students to "recognize the scientifically correct alternatives when explicitly presented to them" than producing their own explanations (Vosniadou et al. 2004, p. 220). The presentation and recognition of the scientifically accepted view is presumed to direct students to reason based on these assumptions and impede the construction of an internal model based on their own beliefs. However, other studies with open-ended questions, which also focused on the issue of consistency versus inconsistency, i.e., inconsistency from a scientist's point of view, showed that students' knowledge about scientific concepts is not highly systematic (diSessa et al. 2004, Nakhleh et al. 2005). The results of the study presented here support this assumption and point out the need for the development of new types of assessment. It has to be reconsidered whether the exclusive use of multiple-choice questions and the merging of items into scales properly captures the apparent diversity of students' ideas. Using open-ended questions in science classes raises other problems, though. The students in the study presented here, for example, had difficulties in expressing themselves in written form. Insufficient language skills might thus entail a distorted picture of the ideas of students, resulting in an underestimation of capacity. Therefore, a triangulation of different assessment methods seems necessary. Limón's (2001, p. 375) claim that "more refined methodological tools should be developed to take account of the learner's prior knowledge" is one of the major challenges for future research on conceptual change.

The problem that students are not able to apply the writing skills they have learned in German classes in chemistry instruction has also been observed by Nieswandt (1997). This is problematic since writing is one of the key competencies students should acquire during their school education. The standards for elementary school education already state that students should have the competency to produce texts, including the processes of planning, writing and editing (Kultusministerkonferenz 2005*b*). The study of Nieswandt (1997) further showed that students have little motivation for writing in chemistry classes. This problem needs to be addressed by an interdisciplinary approach and a cooperation between chemistry and German teachers. Deficient skills and lacking motivation for writing scientific texts is problematic because of two reasons. On the one hand, the distribution of scientific knowledge is essentially dependent on the ability of scientists to publish their research and thoughts in written form. Presenting results is a crucial part of the scientific endeavor to which students should be introduced. On the other hand, writing helps structuring one's own thoughts. It is a powerful way to identify inconsistencies, to clarify thoughts and to solve problems (Flower 1985). Thus, students should learn to appreciate and use writing as a tool which supports their learning process.

### Does the conceptual change text support students in building appropriate ideas about the particle model?

An IRT model was used for estimating students' proficiency based on their answers to the closed-ended items. The IRT model provided an appropriate fit to the data, but also showed that the questionnaire can be improved. More items with a higher degree of difficulty should be added in future research. For testing on text design effects (conceptual change text versus traditional text) an ANCOVA was conducted with the pre-test result as a covariate for the post-test proficiency. Teacher and gender were additionally included as between-subject factors. The ANCOVA revealed a significant effect for text design, favoring the conceptual change text. Regarding the covariate, the analysis gave no indication that high or low prior knowledge students benefited more from one of the treatment conditions. In both groups low knowledge students learned more from reading the texts than high knowledge students. This can be explained in that the texts probably did not provide a lot of new information for high knowledge students. However, it has to be considered that the questionnaire fell short in measuring accurately high levels of proficiency. The proficiency increase of students who already scored high on the pre-test could therefore not be estimated with high confidence. No interaction between text design and teacher or gender was found. Thus, reading the conceptual change text resulted in higher proficiency levels independent of prior knowledge, gender, or teacher. The certainty with which students provided scientifically appropriate answers also showed a higher increase from pre- to post-test for the conceptual change text group.

For investigating text effects on individual misconceptions, a descriptive analysis of individual items was conducted. Results provided valuable insight into text elements that seem to be effective and those that need improvement.

Regarding misconceptions on the environment of the particles, results showed that the conceptual change text helped students to become aware of the idea of empty space between the particles. The rate of readers of the traditional textbook text who changed from model-inconsistent to model-consistent answers was lower. This result indicates that it is important to address misconceptions about the environment of the particles in an explicit way as the conceptual change text did ("Many of us have difficulties in imagining 'nothing' or 'empty space' " ... "Is there air between these particles?") and not only in an indirect way as the traditional text did ("Even when the smallest particles are lying closely side by side, there is empty space between them, i.e., there is nothing between the particles." ("Selbst wenn die kleinsten Teilchen dicht nebeneinander liegen und sich berühren, tritt zwischen ihnen leerer Raum auf, das heißt, dass zwischen den Teilchen nichts ist.") (Eisner et al. 2001, p. 50)). The explicit addressing of a misconception should be followed by a comprehensive explanation *why* the idea of empty space makes sense from a scientific point of view.

The results for the items on the nature of the particles showed a more diverse picture. First, the traditional as well as the conceptual change text helped students efficiently to grasp the idea of constant motion of the particles. We assume that this positive impact is based on the fact that both texts repeatedly refer to the idea of constant motion and use it explicitly to explain everyday phenomena (e.g., dissolving salt in water). Second, the other items which showed high learning effects for conceptual change text readers suggest that it is not only important to address alternative ideas explicitly but also to give concrete examples for the respective general misconception. For instance, the conceptual change text gives a concrete example for the transfer of the feature color to the particles ("... many people think that a copper particle is red and shiny") and argues comprehensively with the help of an analogy why this idea is regarded as a misconception. The traditional text addresses this misconception too, but on a rather abstract level by mentioning that the model makes no statements about a color of the particles of a substance which does not seem to be equally helpful for students. The negative results of both texts for the items referring to the misconception that particles have the same temperature as the substance further support the assumption that it is crucial to give concrete and explicit examples of misconceptions. Although the conceptual change text states that "an individual copper particle is neither red, nor shiny or warm", it does not refer explicitly to the misconception that the particles have the same temperature as the substance. It only states that features such as color or temperature can be perceived with the senses and that these features therefore belong to the world of perception. However, this sentence might be revised since it makes not clear that one's senses perceive how fast heat is conducted by a substance, but may give rise to the idea that one can feel the temperature of a substance by touching it. On the other hand, the low rates of change towards model-consistent answers may be due to the fact that the concepts of temperature and heat themselves are difficult to understand (Linn & Songer 1991). Thus, it might be more appropriate to discuss the misconception of transferring the notion of temperature to the particles later, e.g., when the particle model is used to explain the different states of matter.

Results for the items on model thinking show that both texts supported students in understanding that scientific models are constructs of human minds, that they are only approaches to reality. The metadiscussions about the nature of models, which are present in both texts, seem to be appropriate and effective. The item which refers to the development of new models proved to be problematic for both texts, though. We find low rates of change towards the model-consistent answer for the traditional text and relatively high rates of change towards the model-inconsistent answer for the conceptual change text. These results are presumably due to the fact that both texts do not focus on the aspect of model modification. The conceptual change text does not address the aspect of model modification explicitly and the traditional text only briefly states that the current particle model needs to be expanded in order to explain further phenomena. This confinement is deliberate and sensible since the texts only introduce into the subject. However, regarding the design of texts following the introduction (e.g., modification of the model for explaining the different states of matter), the results here indicate that a metadiscussion about the modification of models seems necessary. A short statement that the model needs to be modified does not seem to be sufficient, and it also seems to be difficult for students to draw the conclusion of changeability of models from a general discussion about models as constructs of human mind. Thus, similar to the observations made for the items on the environment and nature of the particles it seems to be important to discuss crucial aspects of model thinking, including common misconceptions, explicitly and concretely. Another interesting observation concerns the distinction between mind models and concrete models. The traditional text uses a concrete model of an object from the world of experiences (car model) to explain the nature of scientific models. This mixture of genuinely different types of models is probably the reason for the high number of students who agreed on the post-test that – similar to a globe – the spheres in the particle model are a scaled up, simplified representation of how the particles look like in reality, although they had not agreed to this statement on the pre-test.

Generally, we cannot expect that reading a single text is sufficient to engage students in deep and long-lasting conceptual change processes. Teaching units that focus on conceptual change usually comprise many lessons taught over several weeks (e.g., Nieswandt 2001, Vosniadou et al. 2001), and it may even take several teaching units before students are able to apply the scientific concept appropriately (Nieswandt 2001). Texts are only one of several media that can be incorporated by teachers into a comprehensive learning environment. Against this background, it is very positive that a learning effect could be found after a treatment as small as reading a text. Overall, the analysis of the closed-ended questions confirmed the hypothesis that the conceptual change text supported students better in building appropriate ideas about the particle model than a traditional textbook text. The results suggest that the conceptual change text helped students in becoming aware of alternative ideas and in distinguishing them from the scientifically accepted view, i.e., that the text supported students in developing metaconceptual awareness. However, for fostering long-lasting conceptual change processes, particularly with regard to developing the competency of applying the scientific concept adequately, more comprehensive teaching approaches are needed than the treatment presented here.

With regard to instruction and the development of further texts, the analysis of the individual items revealed three main aspects that seem to be relevant for the design of effective conceptual change texts. First, misconceptions need to be addressed by the teacher and by textbooks. It is deceptive to think that by teaching the scientific view and not mentioning alternative ideas students will not develop misconceptions. In the study presented here, 60% of the students thought that air fills the space between the particles and more than half of the students agreed that individual sulfur particles are yellow. These misconceptions were still prevalent at the end of the school year despite the fact that the particle model had been one of the major topics during the school year. Second, misconceptions should not be discussed on a general level, but specific examples should be given explicitly, e.g., "many people think that a copper particle is red and shiny". Third, after having expressed such a specific misconception, the students should be provided with a comprehensive explanation why the respective idea is not consistent with the scientific perspective.

The analysis of the open-ended questions, which asked students to explain two everyday phenomena using the particle model, indicated that the students had problems expressing their thoughts in written language. The results have therefore to be interpreted with caution. Students' answers were categorized into different groups depending on whether and which misconception became apparent in their answer. Three main tendencies were identified. First, the students used the idea of a particulate structure for solids rather than for liquids. Second, the ambiguity of the notion of particle seemed to be problematic. The everyday meaning of particle refers to small macroscopic pieces which conflicts with the scientific idea. Thus, putative misconceptions such as the transfer of color to the particles may partly be due to the fact that students used the word "particle" in its everyday sense. Third, after having read the text the number of students who explained the dissolving process in that the particles or substances react, combine, or melt decreased notably. Here again, there were indications that difficulties in appropriately applying technical terms were the reason for the putatively wrong categorization of the dissolving process. For example, some answers suggested that students used the notion of combining without referring to the formation of a new chemical compound. Regarding the frequencies of answers in the categories, no differences were found between conceptual change text readers and traditional text readers. Thus, the hypothesis that the conceptual change text supported students better in building appropriate ideas about the particle model than a traditional text was not confirmed by the analysis of students' explanation of everyday phenomena. This observation supports the results of other studies which have shown that using scientific concepts to explain everyday phenomena is a major challenge for learners, and that it takes time until students are able to apply concepts appropriately to a wide range of contexts (Linn & Songer 1991, Nieswandt 2001, Parchmann & Schmidt 2003).

#### What do students appreciate about the text and what do they suggest for its improvement?

The analysis of the assessment items showed that both texts had similar mean values of agreement regarding the statement that the text was comprehensible, and that it rose interest to know more about models in science. Whereas the vast majority of students generally agreed to the first item (comprehensibility), only a moderate proportion did so for the latter item (interest to know more about models). The fact that the students rated the traditional text as comprehensible as the conceptual change text supports the choice of this text as control text in the experiment. The high rating for the conceptual change text, on the other hand, shows that the design criteria which focused on text comprehensibility were implemented successfully. The newly developed text was appreciated as comprehensible by almost all students. It has to be considered, though, that the students were already familiar with the topic presented in the texts. A study with novices may show a different picture. Since texts are mostly used for revision in chemistry instruction of secondary level I (see Chapter 5), the study here was purposely conducted after the students had worked on the particle model in the classroom. On the other hand, with regard to a subject as crucial and complex as the particle model, it is neither likely nor desirable that teachers use texts for introducing into the topic. The only moderate degree of agreement to the item that the text rose interest to learn more about scientific models matches the rather low interest in chemistry in general (Kipker 2001, Sasol-Studie 2004). Against this background, the average level of agreement to this item can be seen as satisfactory. With regard to the other three items, we found significant differences between the two groups. Conceptual change text readers showed a higher agreement to all three statements, i.e., that the text was pleasant to read, that it was written in an interesting way, and that they enjoyed reading the text. Thus, the results of the analysis of the evaluative items overall confirmed the hypothesis that students assessed the conceptual change text better than a traditional textbook text.

To get suggestions for improving the conceptual change text, the students were asked what they liked and disliked about the texts. The three most frequently mentioned positive aspects raised by conceptual change text readers were comprehensibility, pleasant and simple language, and the use of examples and comparisons. Traditional text readers most frequently referred to comprehensibility, the use of examples and comparisons, and content-specific aspects. The fact that in both groups the students emphasized that they appreciated the comprehensibility of the text corresponds to the high agreement to the closed-ended item asking for comprehensibility discussed above. Examples and comparisons were also seen as positive aspects in both groups. This indicates that the students were aware that these elements helped them in better understanding the abstract concept of the particle model. The frequency of how often an aspect was raised in the two groups is hard to compare quantitatively, since students were free in what to comment on and in how many aspects they wanted to address. However, some tendencies can be identified when analyzing the categories that differed more than 10%. Conceptual change text readers more often appreciated the comprehensibility of the text and the use of a pleasant and simple language, whereas traditional text readers more often praised the highlighting of key facts and the summary at the end of the text. A summary of the most important facts was not included in the conceptual change text because of its already extended length. The extensive length of the text was also the major point of criticism raised by conceptual change readers. However, a high percentage of traditional text readers raised this issue, too, although the traditional text was shorter than the conceptual change text. An interview study with students might provide additional insight into which parts are too detailed or complicated for students and which parts need shortening. Looking at categories with negative aspects that differed more than 10%, we found that more conceptual change text readers had nothing to criticize about the text, and more traditional text readers referred to the text as uninteresting or boring.

To sum up, the study showed that the developed criteria are effective guidelines for designing conceptual change texts on the particle model. The implementation of the guidelines resulted in a text which supported students in becoming aware of common misconceptions and which was overall assessed as comprehensible and interesting by the students. Issues for improvement are conciseness and the integration of a summary. The study gave further evidence that it is important that textbook texts focus on fostering students' metaconceptual awareness (see also Mikkilä-Erdmann 2001). It seems crucial to address misconceptions explicitly, to give concrete examples, and to explain comprehensively why the according idea is not consistent with the scientific view. The often reported difficulties of applying scientific knowledge to everyday phenomena (Linn & Songer 1991, Nieswandt 2001, Parchmann & Schmidt 2003) were also observed in this study. We further found inconsistency in how students answered to the closed-ended items, and language problems became apparent in the answers to the open-ended questions. This highlights the importance of developing new types of questionnaire tasks with which students' ideas can be measured more properly. It additionally suggests that students need more practice and guidance for developing writing skills in science.

The encouraging results of this study should be followed in further research in other fields than the particle model. Whereas the framework criteria can be used independently, content-specific criteria need to be developed for other topics. Therefor, it seems promising to pursue the approach of combining results from cognitive science with those from instructional research.

# 8

# Summary and perspectives

## Background

The research presented in this thesis focused on texts for chemistry teaching. Studying texts was motivated by two aspects. First, there is a growing need for quality and student-appropriate chemistry texts, since textual material will play an increasingly important role in the chemistry classroom in the future. On the one hand, the results of the PISA study highlighted the relevance of pursuing a more interdisciplinary approach to foster students' reading literacy (e.g., Artelt et al. 2001). Thus, not only language teachers but also science teachers have to take the responsibility to help students in becoming literate, particularly with regard to scientific texts. On the other hand, a more student-centered approach to science instruction is necessary (e.g., Gräsel & Parchmann 2004), and learner-centered instruction is essentially dependent on the use of texts. In this context, texts are not regarded as a substitute for experiments and they should not be used to present students with results they could have figured out by themselves. However, students have to work with textual material when they conduct an Internet research, when they work at learning stations, or when they study science books for a research project. Texts can thus be regarded as an integral part of student-centered instruction, and their use has to be orchestrated with other media into challenging and multifaceted learning environments. The second reason for studying texts refers to the teachers. A study of Daus et al. (2004) suggests that textbooks are one of the most important sources that German chemistry teachers use for planning their teaching. Thus, textbooks could serve as an interface for communicating research results from educational research to practicing teachers. For example, textbooks can inform about common misconceptions and they can provide at least one didactic suggestion of how to address these ideas.

Future research on texts for chemistry teaching could investigate different aspects, such as students' reading competency, linguistic features, or the development and testing of new methods which integrate texts as learning aids. The main focus of the research presented here was the question of how texts can be designed for an approach to chemistry teaching that aims at fostering conceptual change. In other words, we were interested in the development of chemistry expository texts that support students in their learning path from alternative ideas, i.e., from ideas that are not consistent with the scientific view, to scientific ideas, i.e., to ideas that are currently accepted by the scientific community. Addressing alternative ideas is crucial for building scientific understanding. Non-addressing of these ideas is regarded as a major source for the often observed learning difficulties in science (Duit 1995*a*, Treagust et al. 2000).

For the development of such "conceptual change texts" it is important to know whether and how these texts may actually have an impact on the chemistry classroom. Generally, there are two ways how texts can influence teaching practice: They are either incorporated into the class, i.e., the students use the texts to support their learning, or they are applied for the preparation of the class, i.e., the teachers use the texts to plan their instruction.

## Summary

For investigating how texts are incorporated into the classroom as learning aids for students (secondary level I), a postal questionnaire survey with 240 German Gymnasium chemistry teachers from four different federal states was conducted (see Chapter 5). It was found that texts are seldom used in the classroom and that the main purpose of text use is revision and consolidation, often at home. With regard to the use of conceptual change texts, it should thus be easy for most of the teachers to integrate them into their teaching, since conceptual change texts are very apt to be used for consolidation. For example, after having worked on a specific subject the students may read a conceptual change text on the respective topic either at home or at school. In the following lesson, there could be a metadiscussion about the contents of the text, particularly about the similarities and differences between alternative and scientific ideas. Such discussions are intended to support students in developing metaconceptual awareness and thus in deepening their understanding of the scientific concept (e.g., Vosniadou & Ioannides 1998). In order to encourage a more diverse integration of texts into the classroom (e.g., learning stations, jigsaw) chemistry teachers should be offered the opportunity to attend professional development courses or workshops about this topic.

For investigating how textbook texts are used by teachers for preparing their teaching, the chemistry teachers of the survey were asked to rate the relevance of textbooks for specific aspects of their lesson planning and to estimate the importance of different resources used for this purpose (see Chapter 6). The answers showed that textbooks are appreciated as valuable resources for suggestions on content-specific and everyday life related aspects that might be included into a new teaching unit. The study further demonstrated that textbooks are one of the most important sources for the preparation of chemistry instruction, which confirmed the results of Daus et al. (2004). Textbooks could thus be used as a medium to inform teachers about common misconceptions and to offer didactic suggestions how to deal with them.

Against this background, a qualitative content analysis of the introductory texts on the particle model found in two popular chemistry textbooks was conducted (see Chapter 6). We sought to investigate whether and how alternative ideas are addressed in the expository texts (e.g., Roseman et al. 1997). The analysis showed that common misconceptions are addressed explicitly in only one of the texts, although partly on a rather abstract level. Both texts present anomalous data, i.e., phenomena with an unexpected outcome, intended to challenge a common idea of students. However, there is only one example where the observation which students are assumed to expect is stated explicitly. In most of the other cases, the anomaly is highlighted by indicators. Metaconceptual prompts urging students to reflect on their own ideas or on common misconceptions are missing in both textbook texts. Thus, although the textbooks attempt to address common ideas of students, principles of conceptual change instruction are not sufficiently taken into account in traditional texts. The third study of the thesis adhered to this aspect in that it focused on the development of new conceptual change texts.

For developing design criteria for conceptual change texts, a multidimensional approach was employed (see Chapter 7). First, we sought to define framework criteria which can serve as guidelines for designing conceptual change texts in general. A literature review on research on conceptual change (e.g., Chi et al. 1994, Chinn & Brewer 1993, diSessa 2002, Duit 1999, Halldén 1999, Limón 2001, Posner et al. 1982, Vosniadou 1994, see Chapter 2) and text comprehensibility (e.g., Artelt et al. 2005, Ballstaedt 1997, Graesser et al. 2002, Guzzetti et al. 1993, Kintsch & van Dijk 1978, Langer et al. 2002, Mikkilä-Erdmann 2001, Schnotz 1994, Schüttler 1994, see Chapter 3) was conducted. Second, the results of the teacher survey described above were taken into account, since we intended to create guidelines which consider the actual patterns of text use that are currently prevalent in the chemistry classroom. We additionally wanted to benefit from the expertise of practitioners and thus asked the teachers of the survey to assess current textbook texts and to give suggestions for their improvement (see Chapter 5).

The compiled framework criteria were implemented in an expository text for the introductory chemistry course. We chose the particle model as the topic for the text, since it is a key concept in chemistry teaching about which a lot of misconceptions are known (e.g., Fischler & Lichtfeldt 1997, Mikelskis-Seifert 2002, Parchmann & Schmidt 2003, see Section 4.2). For designing a text on the particle model, content-specific criteria needed to be defined in addition to the framework criteria. Theories of conceptual change provided by cognitive science (e.g., Vosniadou 1994) were used to analyze the most common misconceptions about the particle model (see Section 2.3 and Section 7.2.2). Based on the results of this analysis, literature on instructional approaches for the introduction of this concept was reviewed. This method yielded content-specific criteria for the design of the text (see Chapter 4 and Section 7.2.2).

Finally, a text was designed according to the developed criteria and evaluated in an empirical study with 214 seventh and eighth graders. For this study, a pre-post-test design was chosen with a treatment group reading the conceptual change text and a control group reading a traditional textbook text. The choice for the traditional text was based on the textbook analysis described above. The text which addressed a range of misconceptions was used for comparison. Both the seventh and the eighth graders were in their first year of chemistry education and they were familiar with the particle model. The experiment took place in a regular classroom setting. In the first week, the students took a pre-test and in the second week, they were randomly assigned to either read the conceptual change or the traditional textbook text. Immediately after having read the text, the students worked on the post-test. The analysis of the test items was based on a dichotomous Item Response Theory model which generally fitted the data well. Shortcomings were found concerning the estimation of the proficiency of high performing students, which point to possible improvements in future research.

The results of the analysis showed that the conceptual change text supported students in becoming aware of common misconceptions. They further suggested that it is important to address misconceptions explicitly, to give specific examples for misconceptions, and to provide comprehensive explanations why the respective idea is not consistent with the scientific view. The students generally appreciated the conceptual change text as interesting and comprehensible. Compared to the traditional textbook text, the conceptual change text overall succeeded better in addressing common misconceptions, and it was demonstrated to be more student-appropriate.

Explaining everyday phenomena using the particle model remained difficult for the students, even after having read the conceptual change text. This result is consistent with the repeatedly made observation that learning takes time, and that it is difficult for students to explain everyday phenomena with the help of scientific concepts (Bransford et al. 2000*e*, Nieswandt 2001). The answers to the open-ended questions of the tests further suggested that the students had problems in expressing themselves in written form using the scientific language (see also Nieswandt 1997).

Overall, the study indicates that the compiled guidelines can be used effectively for designing conceptual change texts for chemistry instruction. However, reading one conceptual change text will hardly result in metaconceptual understanding, i.e., in the awareness of different concepts *and* in the competency to apply the concepts appropriately in different contexts. Texts can only be one of several teaching materials that have to be orchestrated by the teacher.

## Perspectives

For future research, it would be interesting to develop content-specific criteria for other topics than the particle model, following the path of combining results from cognitive science with those obtained from instructional approaches. Different conceptual change texts could be designed according to the framework and the respective content-specific criteria. The following research questions should be investigated: Do the texts support students in building metaconceptual awareness? Can a long-term use of conceptual change texts contribute to the development of the competency to apply scientific concepts in everyday contexts? How do teachers like the conceptual change texts? Do conceptual change texts influence teachers' lesson planning so that alternative ideas become a more important part of their teaching? How can conceptual change texts be integrated effectively into the classroom? Do they encourage metaconceptual discussions? For investigating these aspects a triangulation of research methods, such as questionnaires, interview studies, and classroom observations, seems necessary.

To develop conceptual change texts collaboratively with teachers, professional development courses might be offered. Such courses are likely to appeal to a proportion of chemistry teachers as demonstrated by the analysis of the teacher survey (see Chapter 5). Teachers who work actively with texts in the classroom seem to be particularly dissatisfied with current textbook texts and may thus be interested in learning more about how to improve or write chemistry texts for their students.

In the following, a three-phase schedule is suggested as one possibility of how to implement these courses. In the first phase, the teachers are introduced to the idea of conceptual change texts. The framework criteria are presented and discussed (e.g., Why is it important to address misconceptions?). A conceptual change text is given to the teachers as a concrete example of how the guidelines can be translated into a text. Next, the development and implementation of the content-specific criteria is explained and discussed, based on the topic of the text which was chosen for the course. In the second phase of the course, the teachers work in small groups and they are encouraged to write a conceptual change text on their own. The groups are first asked to choose a topic for the text and to brainstorm common misconceptions about the respective concept. In addition, a list with common misconceptions detected by research may be given to the teachers. Once the groups have agreed on which misconceptions they would like to address in the text, they develop content-specific criteria based on their teaching experiences. A selection of articles with didactic suggestions for teaching the respective concept might be supplied, too. Finally, a text is written and the teachers are encouraged to study the application of the text in their classrooms. In the third phase of the course, the teachers meet again to discuss and reflect on how the integration of the text has worked. They might additionally discuss how conceptual change texts in general can be used for planning chemistry classes, including texts that are written by other authors. In this context, it might be useful to introduce the model of didactic reconstruction, which emphasizes the systematic correlation of scientific ideas and students' ideas as the basis for successful teaching and learning. Thus, both the learner's and the scientific perspective are seen as equal components for the preparation of science instruction (Kattmann & Gropengießer 1996).

Since the use of textual material and the addressing of students' ideas are important aspects for lasting learning, it is hoped that a diverse and appropriate use of conceptual change texts will contribute to a more challenging and interesting chemistry classroom.

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# A

# Original items in German

| Purpose of text use – items | M | (SD) |
|---|---|---|
| Zur Erarbeitung neuer Inhalte setze ich im Unterricht Texte ein. | 2.03 | (± 0.80) |
| In verwende Texte als Einstieg in ein neues Thema. | 2.08 | (± 0.84) |
| Zur Wiederholung/Festigung des erworbenen Wissens lasse ich die Schüler/-innen Texte lesen. | 2.76 | (± 0.98) |
| Ich setze Texte ein, um den Schülern/-innen Alltagsbezüge der erarbeiteten chemischen Inhalte aufzuzeigen. | 2.62 | (± 1.01) |

Table A.1: Purpose of text use. Mean value (M), standard deviation (SD).

| **Item text** | **Factors** | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Ich fordere die Schüler/-innen auf, einen längeren Text in Abschnitte zu gliedern. | **.753** | | |
| Ich fordere die Schüler/-innen auf, einen längeren Text systematisch zu bearbeiten (z.B. Überblick verschaffen, Abschnitte festlegen, Fragen zum Inhalt des Abschnittes stellen, gründlich lesen, etc.) | **.751** | .324 | |
| Ich fordere die Schüler/-innen auf, eigene Fragen an einen Text zu formulieren. | **.716** | | |
| Ich fordere die Schüler/-innen auf, Überschriften/Schlagwörter zu einzelnen Textabschnitten zu finden. | **.710** | | |
| Ich fordere die Schüler/-innen auf, zentrale Begriffe und Schlüsselstellen eines Textes herauszufinden und zu markieren. | **.709** | .344 | |
| In meinem Unterricht lesen die Schüler/-innen Texte in Stillarbeit. | | **.759** | |
| Bei der Durchführung von Gruppen-/Partnerarbeit (z.B. Lernzirkel) erhalten die Schüler/-innen Texte als Informationsquelle. | | **.741** | |
| Ich rege die Schüler/-innen an, einen Text in Kleingruppen zu bearbeiten (z. B. Aufgaben zum Text). | | **.724** | |
| Ich gebe den Schülern/-innen zu einem Text Fragen vor, die sie mit Hilfe des Textes beantworten sollen. | .321 | **.655** | |
| Ich fordere die Schüler/-innen auf, nach dem Lesen eines Textes den Inhalt mit eigenen Worten wiederzugeben. | | **.643** | |
| Schüler/-innen, die krank waren, fordere ich auf, die versäumten Inhalte mit Hilfe des Schulbuchs aufzuarbeiten. | | | **.743** |
| Ich gebe den Schülern/-innen Kapitel aus dem eingeführten Schulbuch bzw. andere Texte an die Hand, mit deren Hilfe sie sich auf einen Test/eine Kursarbeit vorbereiten können. | | | **.680** |
| Schüler/-innen, die im Unterricht Verständnisschwierigkeiten zeigen, fordere ich auf, im Schulbuch die Inhalte noch einmal nachzulesen. | | | **.654** |
| Zur Bearbeitung schriftlicher Hausaufgaben gebe ich den Schülern/-innen Kapitel aus dem eingeführten Schulbuch bzw. andere Texte an die Hand. | | | **.634** |
| Ich rege die Schüler/-innen an, zu Hause Texte zur Nachbereitung eines Themas zu verwenden. | .350 | | **.504** |

Table A.2: Principal component analysis with varimax rotation for the use of texts in chemistry instruction. Factor loadings for the three-factor solution. Factor loadings $<0.3$ were suppressed. Loadings in bold indicate the assignment of the items to the factors.

| Item text | Assessment<br>M | <br>(SD) | Expectation<br>M | <br>(SD) | t-test<br>t | <br>p |
|---|---|---|---|---|---|---|
| Die Schüler/-innen finden die Schulbuchtexte interessant. | 2.20 | (± 0.62) | 3.64 | (± 0.59) | -25.38 | < .001 |
| Die Schüler/-innen haben keine Verständnisschwierigkeiten beim Lesen von Schulbuchtexten mit bereits bekannten Inhalten (d.h. zur Wiederholung). | 2.92 | (± 0.76) | 3.76 | (± 0.46) | -14.11 | < .001 |
| Die Schüler/-innen haben keine Verständnisschwierigkeiten beim Lesen von Schulbuchtexten mit neuen Inhalten (d.h. zur selbstständigen Erarbeitung von Inhalten in Einzel- oder Gruppenarbeit). | 2.11 | (± 0.69) | 3.48 | (± 0.65) | -23.07 | < .001 |

Table A.3: Assessment of and expectations for textbook texts from the teachers' perspective. Item text, mean value (M), standard deviation (SD), two-tailed paired t-test.

| Item text | Assessment<br>M | <br>(SD) | Expectation<br>M | <br>(SD) | t-test<br>t | <br>p |
|---|---|---|---|---|---|---|
| Ich habe den Eindruck, dass die Schulbuchtexte den Schülern/-innen bei ihren Verständnisschwierigkeiten helfen. | 2.46 | (± 0.62) | 3.60 | (± 0.53) | -22.97 | < .001 |
| Ich habe den Eindruck, dass die Schulbuchtexte den Schülern/-innen nicht nur Faktenwissen, sondern auch Zusammenhänge vermitteln. | 2.62 | (± 0.76) | 3.70 | (± 0.52) | -19.63 | < .001 |
| Ich habe den Eindruck, dass die Schulbuchtexte den Schülern/-innen themenübergreifende Zusammenhänge vermitteln. | 2.22 | (± 0.74) | 3.36 | (± 0.68) | -18.00 | < .001 |

Table A.4: Assessment of and expectations for textbook texts from the teachers' perspective. Item text, mean value (M), standard deviation (SD), two-tailed paired t-test.

| **Item text** | **Factors** | | | | | |
|---|---|---|---|---|---|---|
| | **Assessment (1. Factor analysis)** | | | **Expectation (2. Factor analysis)** | | |
| | A1 | A2 | A3 | E1 | E2 | E3 |
| Die Sätze sind einfach (z.B. keine verschachtelten Nebensätze). | **.723** | | | **.749** | | |
| Die Schulbuchtexte enthalten keine Nebensächlichkeiten oder irrelevanten Informationen. | **.706** | | | **.595** | | |
| Die Sätze sind kurz. | **.704** | | | **.746** | | |
| Die Schulbuchtexte sind in übersichtliche Absätze gegliedert. | **.637** | | | **.539** | | .357 |
| Die Anzahl der verwendeten Fachbegriffe ist den Kenntnissen der Schüler/-innen angemessen. | **.621** | | | **.621** | | |
| Innerhalb eines Schulbuchtextes treten keine inhaltlichen Lücken oder Brüche auf. | **.554** | | | **.530** | | |
| Die Schulbuchtexte beziehen die Erlebniswelt der Schüler/-innen ein. | | **.838** | | | .310 | **.641** |
| Die Schulbuchtexte enthalten Beispiele, die an die alltäglichen Erfahrungen der Schüler/-innen anknüpfen. | | **.819** | | | | **.772** |
| Die Schulbuchtexte gehen auf Erfahrungen und Vorstellungen ein, die die Schüler/-innen zu dem Thema aus dem Alltag mitbringen. | | **.771** | | | | **.757** |
| Den Schulbuchtexten sind Fragen zum Einstieg vorangestellt. | | | **.646** | | **.745** | |
| Den Schulbuchtexten ist eine Liste mit den Lehrzielen des Textes vorangestellt. | | | **.644** | | **.729** | |
| Den Schulbuchtexten ist ein Vorspann vorangestellt, der es schafft, eine Brücke vom Vorwissen der Schüler/-innen zu den Textinhalten zu schlagen. | | | **.638** | | **.621** | .383 |
| Die Schulbuchtexte gehen auf fehlerhafte Vorstellungen ein, die viele Schüler/-innen zu dem entsprechenden Thema besitzen bzw. entwickeln. | | | **.582** | | **.653** | |
| In die Schulbuchtexte sind Fragen/Aussagen integriert, die die Neugier der Schüler/-innen auf die nachfolgenden Textinhalte wecken. | | .331 | **.447** | | **.573** | |

Table A.5: Principal component analysis with varimax rotation for teachers' assessment of and their expectations for textbook texts. Factor loadings for the three-factor solution. Factor loadings <0.3 were suppressed. Loadings in bold indicate the assignment of the items to the factors.

| Item text | M | (SD) |
|---|---|---|
| Schulbücher geben mir Anregung für die Auswahl inhaltlicher Aspekte zur Gestaltung der Einheit | 3.48 | (± 0.66) |
| Schulbücher geben mir Anregung für die Reihenfolge, mit der ich die Einheit behandele. | 2.73 | (± 0.94) |
| Schulbuchtexte dienen mir als Anregung für den Hefteintrag der Schüler/-innen. | 2.65 | (± 0.89) |
| Zur schülergrechten Erklärung von Inhalten verwende ich die in Schulbüchern vorgestellten Erläuterungen. | 2.44 | (± 0.85) |
| Ich gehe im Unterricht auf die Alltagsbezüge ein, die in Schulbüchern angesprochen werden. | 3.24 | (± 0.73) |

Table A.6: Distribution of answers to the question: Which specific role do textbooks play for the planning of a new teaching unit? Mean value (M), standard deviation (SD).

| Item text | L | D |
|---|---|---|
| Zwischen den Teilchen, die einen Stoff bilden, ist nichts. | env3 | 595 |
| Ähnlich wie ein Globus eine verkleinerte und vereinfachte Darstellung der Erde ist, sind die Kugeln in dem dir bekannten Teilchenmodell eine vergrößerte und vereinfachte Darstellung davon, wie die Teilchen in Wirklichkeit aussehen. (r) | mod4 | 594 |
| Die einzelnen Teilchen, aus denen gefrorenes Wasser aufgebaut ist, haben eine niedrigere Temperatur als die Teilchen, aus denen flüssiges Wasser aufgebaut ist. (r) | nat5 | 578 |
| Zwischen den einzelnen Teilchen, die einen Stoff bilden, ist Luft. (r) | env1 | 546 |
| Wenn Wasser auf 30°C erhitzt wird, dann haben die einzelnen Wasserteilchen eine Temperatur von 30°C. (r) | nat4 | 527 |
| Ein einzelnes Schwefelteilchen ist gelb. (r) | nat2 | 524 |
| Wird ein Ballon vollständig mit dem Gas Helium gefüllt, so ist zwischen den einzelnen Heliumteilchen Luft. (r) | env4 | 470 |
| Die Eigenschaft "Glanz" gehört nicht zu einem einzelnen Silberteilchen. | nat3 | 470 |
| Die Teilchen sind von ganz anderer Art als alles, was wir aus unserer Erfahrung im Alltag kennen. | nat7 | 455 |
| Das dir bekannte Teilchenmodell ist die einzige Möglichkeit, wie man sich die Teilchen vorstellen kann. (r) | mod6 | 443 |
| Die Teilchen haben dieselben Eigenschaften wie der Stoff, den sie bilden. (r) | nat1 | 411 |
| Ein Teilchenmodell, das sehr viele Beobachtungen erklären kann, beschreibt, wie die Teilchen in Wirklichkeit aussehen. (r) | mod5 | 408 |
| Wenn wir Beobachtungen machen, die wir mit dem dir bekannten Teilchenmodell nicht mehr erklären können, ist es sinnvoll, ein neues Modell zu entwickeln. | mod3 | 405 |

Table A.7: Item ranking based on difficulty estimates. Item text, Label (L), Difficulty estimate (D). Higher values indicate higher difficulty. (r) indicates recoded items.

| Item text | L | D |
|---|---|---|
| Die Vorstellung, die wir uns von den Teilchen machen, ist eine menschliche Erfindung, die gezielt zur Deutung bestimmter Beobachtungen dienen soll. | mod1 | 402 |
| Die Teilchen, die den Stoff Zucker bilden, sind winzig kleine, weiße Zuckerstückchen. (r) | nat6 | 388 |
| Es kann sein, dass die Teilchen andere Eigenschaften haben, als wir es in dem dir bekannten Teilchenmodell annehmen. | mod2 | 378 |
| Da eine rollende Kugel nach einiger Zeit aufhört sich zu bewegen, hören auch die Teilchen irgendwann auf sich zu bewegen. (r) | nat8 | 367 |
| Zwischen einzelnen Wasserteilchen befindet sich Wasser in flüssiger Form. (r) | env2 | 350 |

Table A.7 (continued)

**Tea-/ Sugar-Question**

*“Nimm getrocknete Teeblätter und übergieße sie mit heißem Wasser.*
*Es entsteht ein herrlich aromatisches, wohlschmeckendes Getränk.”*

**A** Wie erklärst du dir mit Hilfe des Teilchenmodells, dass aus braunen, getrockneten Blättern und einer klaren Flüssigkeit (Wasser) durch dieses Verfahren Tee hergestellt wird?

**B** Beschreibe mit Hilfe des Teilchenmodells, was beim Lösen von Zucker in Tee passiert.

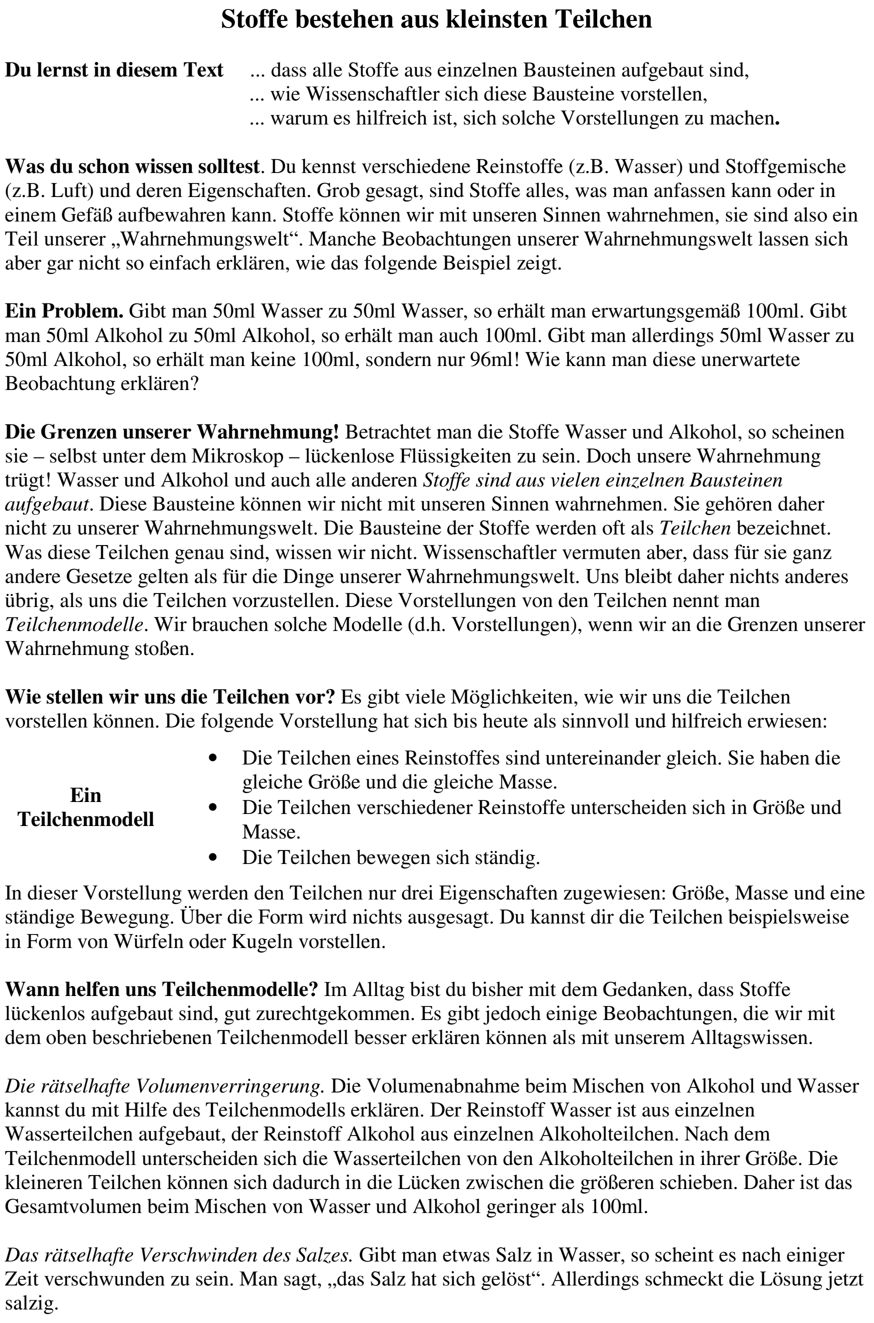
Table A.8: Open-ended application questions.

| | **CC** | | **TT** | |
|---|---|---|---|---|
| Item text | M | (SD) | M | (SD) |
| Ich finde den Text verständlich. | 3.67 | (± 0.59) | 3.50 | (± 0.71) |
| Ich finde den Text angenehm zu lesen. | 3.38 | (± 0.80) | 2.97 | (± 0.88) |
| Ich finde, dass der Text interessant geschrieben ist. | 3.02 | (± 0.98) | 2.61 | (± 1.04) |
| Es hat mir Spaß gemacht, den Text zu lesen. | 2.70 | (± 0.99) | 2.21 | (± 0.94) |
| Der Text hat in mir das Interesse geweckt, mehr über Modellvorstellungen in den Naturwissenschaften zu erfahren. | 2.35 | (± 1.04) | 2.15 | (± 0.93) |

Table A.9: Students' assessment of the text. Mean value (M), standard deviation (SD).

# B

# Conceptual change text in German



## Stoffe bestehen aus kleinsten Teilchen

**Du lernst in diesem Text** ... dass alle Stoffe aus einzelnen Bausteinen aufgebaut sind,
... wie Wissenschaftler sich diese Bausteine vorstellen,
... warum es hilfreich ist, sich solche Vorstellungen zu machen**.**

**Was du schon wissen solltest**. Du kennst verschiedene Reinstoffe (z.B. Wasser) und Stoffgemische (z.B. Luft) und deren Eigenschaften. Grob gesagt, sind Stoffe alles, was man anfassen kann oder in einem Gefäß aufbewahren kann. Stoffe können wir mit unseren Sinnen wahrnehmen, sie sind also ein Teil unserer „Wahrnehmungswelt“. Manche Beobachtungen unserer Wahrnehmungswelt lassen sich aber gar nicht so einfach erklären, wie das folgende Beispiel zeigt.

**Ein Problem.** Gibt man 50ml Wasser zu 50ml Wasser, so erhält man erwartungsgemäß 100ml. Gibt man 50ml Alkohol zu 50ml Alkohol, so erhält man auch 100ml. Gibt man allerdings 50ml Wasser zu 50ml Alkohol, so erhält man keine 100ml, sondern nur 96ml! Wie kann man diese unerwartete Beobachtung erklären?

**Die Grenzen unserer Wahrnehmung!** Betrachtet man die Stoffe Wasser und Alkohol, so scheinen sie – selbst unter dem Mikroskop – lückenlose Flüssigkeiten zu sein. Doch unsere Wahrnehmung trügt! Wasser und Alkohol und auch alle anderen *Stoffe sind aus vielen einzelnen Bausteinen aufgebaut*. Diese Bausteine können wir nicht mit unseren Sinnen wahrnehmen. Sie gehören daher nicht zu unserer Wahrnehmungswelt. Die Bausteine der Stoffe werden oft als *Teilchen* bezeichnet. Was diese Teilchen genau sind, wissen wir nicht. Wissenschaftler vermuten aber, dass für sie ganz andere Gesetze gelten als für die Dinge unserer Wahrnehmungswelt. Uns bleibt daher nichts anderes übrig, als uns die Teilchen vorzustellen. Diese Vorstellungen von den Teilchen nennt man *Teilchenmodelle*. Wir brauchen solche Modelle (d.h. Vorstellungen), wenn wir an die Grenzen unserer Wahrnehmung stoßen.

**Wie stellen wir uns die Teilchen vor?** Es gibt viele Möglichkeiten, wie wir uns die Teilchen vorstellen können. Die folgende Vorstellung hat sich bis heute als sinnvoll und hilfreich erwiesen:

**Ein Teilchenmodell**

- Die Teilchen eines Reinstoffes sind untereinander gleich. Sie haben die gleiche Größe und die gleiche Masse.
- Die Teilchen verschiedener Reinstoffe unterscheiden sich in Größe und Masse.
- Die Teilchen bewegen sich ständig.

In dieser Vorstellung werden den Teilchen nur drei Eigenschaften zugewiesen: Größe, Masse und eine ständige Bewegung. Über die Form wird nichts ausgesagt. Du kannst dir die Teilchen beispielsweise in Form von Würfeln oder Kugeln vorstellen.

**Wann helfen uns Teilchenmodelle?** Im Alltag bist du bisher mit dem Gedanken, dass Stoffe lückenlos aufgebaut sind, gut zurechtgekommen. Es gibt jedoch einige Beobachtungen, die wir mit dem oben beschriebenen Teilchenmodell besser erklären können als mit unserem Alltagswissen.

*Die rätselhafte Volumenverringerung.* Die Volumenabnahme beim Mischen von Alkohol und Wasser kannst du mit Hilfe des Teilchenmodells erklären. Der Reinstoff Wasser ist aus einzelnen Wasserteilchen aufgebaut, der Reinstoff Alkohol aus einzelnen Alkoholteilchen. Nach dem Teilchenmodell unterscheiden sich die Wasserteilchen von den Alkoholteilchen in ihrer Größe. Die kleineren Teilchen können sich dadurch in die Lücken zwischen die größeren schieben. Daher ist das Gesamtvolumen beim Mischen von Wasser und Alkohol geringer als 100ml.

*Das rätselhafte Verschwinden des Salzes.* Gibt man etwas Salz in Wasser, so scheint es nach einiger Zeit verschwunden zu sein. Man sagt, „das Salz hat sich gelöst“. Allerdings schmeckt die Lösung jetzt salzig.

Figure B.1: Conceptual Change text.

Das Salz kann also nicht verschwunden sein. Das Teilchenmodell kann auch hier eine gute Erklärung liefern. Das Lösen des Salzes kann man sich so vorstellen: Salz besteht aus einzelnen Salzteilchen, Wasser aus einzelnen Wasserteilchen. (Vorsicht! Vielen denken jetzt an winzigst kleine Salzkörnchen. Der Begriff „Teilchen“ meint aber die Grundbausteine, aus denen der Stoff Salz aufgebaut ist. Auch winzigst kleine Salzkörnchen bestehen noch aus sehr vielen dieser Bausteine.) Nach dem Teilchenmodell bewegen sich die Teilchen ständig. Einige Wasserteilchen bewegen sich zwischen die Salzteilchen und trennen einzelne Salzteilchen von den anderen ab. Die abgetrennten Salzteilchen bewegen sich zwischen die umgebenden Wasserteilchen. Nach und nach werden so alle Salzteilchen voneinander getrennt. Der Stoff Salz ist jetzt nicht mehr sichtbar. Die Salzteilchen sind zwischen den Wasserteilchen gleichmäßig verteilt. Dadurch schmeckt die gesamte Lösung salzig.

Denk immer daran, dass das oben beschriebene Teilchenmodell nur eine Vorstellung ist. Es hilft uns, solche Beobachtungen zu erklären. Es bedeutet nicht, dass es wirklich so ist!

**Haben die Teilchen eine Farbe?** Welche Farbe hat deiner Meinung nach ein Kupferteilchen? Der Stoff Kupfer ist rot und glänzend. Daher denken viele, dass ein Kupferteilchen rot und glänzend ist. Aber Achtung! Eigenschaften wie Farbe, Glanz und Temperatur können wir mit unseren Sinnen wahrnehmen. Sie gehören zu den Stoffen, zu unserer Wahrnehmungswelt. Die Bausteine der Stoffe gehören aber nicht zu unserer Wahrnehmungswelt. Eigenschaften wie Farbe, Glanz oder Temperatur machen daher im Zusammenhang mit den Teilchen keinen Sinn. Ein Beispiel zum Vergleich: Ein Haus hat die Eigenschaft, dass Menschen darin wohnen können. Ein einzelner Stein hat diese Eigenschaft nicht. Erst alle Steine zusammen sind für diese Eigenschaft des Hauses verantwortlich. Ähnlich ist ein einzelnes Kupferteilchen nicht rot, glänzend oder warm. Erst sehr, sehr viele Teilchen zusammen formen den Stoff Kupfer. Und erst sehr, sehr viele Teilchen zusammen sind für Eigenschaften wie Farbe, Glanz oder Temperatur verantwortlich. (Du wirst später noch lernen, wie man das Entstehen von Stoffeigenschaften wie z.B. Farbe erklären kann.) Ein einzelnes Teilchen hat nicht die gleichen Eigenschaften wie der Stoff! Es ist wichtig, dass du dir klar machst, dass wir Beobachtungen, die wir mit Dingen im Alltag machen, nicht auf die Teilchen übertragen können!

**Was ist zwischen den Teilchen?** Wissenschaftler konnten sich lange nicht vorstellen, dass Stoffe aus einzelnen Teilchen aufgebaut sind. Warum fiel ihnen das so schwer? Ganz einfach, sie konnten sich nicht vorstellen, dass es ein Vakuum gibt. Du kennst sicher vakuumverpackte Lebensmittel oder du hast schon von Vakuumpumpen gehört. Sie pumpen Luft aus einem Behälter, so dass in ihm ein Vakuum entsteht. Da die Luft herausgepumpt wurde, ist in dem Behälter nichts mehr, auch keine Luft. Im Alltag beobachten wir dagegen, dass zwischen allen Dingen Luft ist. Daher fällt es den meisten von uns schwer, sich „Nichts“ oder einen „leeren Raum“ vorzustellen. Versuche trotzdem, den folgenden Gedankengang zu verstehen: Die Luft ist ein Stoff. Daher besteht sie aus vielen einzelnen Teilchen. Befindet sich zwischen diesen Teilchen Luft? Nein, denn die einzelnen Teilchen bilden ja erst den Stoff Luft. Das heißt, zwischen den Teilchen ist nichts, nur leerer Raum! Auch für alle andere Stoffe wie z.B. Kupfer gilt: *Zwischen den Teilchen ist nichts*.
Was ist demnach zwischen Wasserteilchen? Wie hast du dir das vorher vorgestellt?

**Gibt es ein „richtiges“ Modell?** Manche fragen, ob es ein „richtiges“ Teilchenmodell gibt – ein Modell, das beschreibt, welche Eigenschaften die Teilchen in Wirklichkeit haben. Überlege dir hierzu aber Folgendes: Wir entwerfen naturwissenschaftliche Modelle ja gerade dann, wenn wir an die Grenzen unserer Wahrnehmung stoßen. Modelle können daher nicht beschreiben, wie es wirklich ist. Sie können immer nur eine *Annäherung* an die Wirklichkeit sein. Ein Teilchenmodell kann daher nicht „richtig“ sein. Wenn allerdings deine Vorstellung von den Teilchen viele Beobachtungen erklären kann, dann ist sie ein besseres Modell als eine Vorstellung, die nur wenige Beobachtungen erklären kann.

**Zum Abschluss.** Schau dir noch einmal jeden Abschnitt dieses Textes an. Welche wichtige Idee wird in dem jeweiligen Abschnitt vorgestellt? Überlege, ob diese Ideen mit deinen eigenen Ideen übereinstimmen.

Figure B.1 (continued)