Chapter 12
Contexts as Learning Catalysts for Students and Teachers: Approaches and Exemplary Results from the Projects *Chemie im Kontext* and CHEMOL

Ilka Parchmann, Nina Dunker and Wiebke Endres

Introduction and Background

Active learning for students' demands successful stimuli and supporting structures. The teaching tradition in German classrooms often uses experiments as stimuli. However, the results of empirical studies show that experiments rather enhance "activities of hands" than "activities of minds" (Lunetta 1998; Euler 2002; von Aufschneiter and Riemeier 2005). Students carry out experiments as "cookbook-recipes," not as a scientific approach to gain new insights, following certain rules and processes as shown in Fig. 12.1.

Additionally, students do not connect experiments and basic concepts to phenomena in daily life and classroom teaching with just a high number of experiments does not automatically lead to successful learning processes either (Prenzel et al. 2007). We can therefore state that experiments on their own do not work as "catalysts" for active learning, initiating the development of applicable and sustainable chemical knowledge and competencies.

The projects *Chemie im Kontext* for secondary level and CHEMOL for primary level use contexts derived from the students' daily-life experiences or contexts connected to important societal issues to raise questions which can be investigated by groups, using different approaches and techniques. The active learning of the students is supported by scaffolding material and a variety of teaching and learning methods, involving different roles for teachers and students.

I. Parchmann
IPN, Kiel, Germany
e-mail: parchmann@ipn.uni-kiel.de

N. Dunker (✉)
University of Bremen, Bremen, Germany
e-mail: dunker@uni-bremen.de

W. Endres
University of Oldenburg, Oldenburg, Germany

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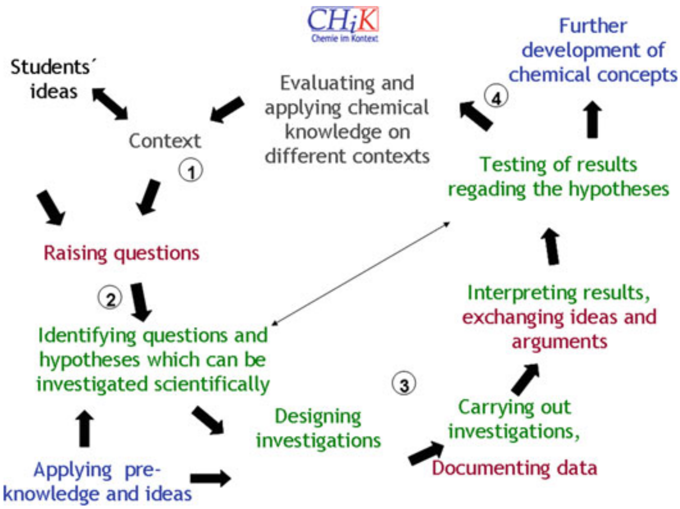

Fig. 12.1 Procedures of an experimental scientific research approach (The numbers refer to the four phases of *Chemie im Kontext*, see below.)

The implementation of both projects into school practice was supported by the involvement of teachers or teacher students already in the design process of the material (Parchmann et al. 2006; Steffensky and Parchmann 2007). This cooperation of perspectives from research and practice assured the ecological and theoretical validity of the conceptual framework and the material. Therefore, the term "active learning" can also be applied to the learning of the involved teachers and researchers, who learned from each other in a "symbiotic" way (Parchmann et al. 2006).

This chapter of the book will describe the structure of both projects, give examples of teaching and learning processes and discuss exemplary results from qualitative and quantitative research studies.

Chemie im Kontext

Active Learning for Students—Contexts as Learning Catalysts

The conceptual framework of *Chemie im Kontext* is based on three principles [for further information on Chemie im Kontext (CHiK) see Parchmann et al. 2006; Nentwig et al. 2007]:

1. **Context-based learning**: Learning environments are considered "in context," when learners acquire knowledge and competence on a need-to-know-basis in

dealing with a relevant issue, starting with their questions and ideas. Examples are: "Food design—why, how and where?;" "Carbon dioxide and climate change?;" "Materials by design;" "A mouth full of chemistry."

2. **Development of basic concepts**: To develop a basic knowledge foundation that can be applied to new contexts and situations, the main principles of chemistry must be derived and abstracted from the contexts. These principles are described as "basic concepts," they structure and summarize the factual knowledge (see the basic concepts of the National Standards).
3. **Variety of teaching and learning methods**: A variety of teaching and learning methods is one of the key elements for a successful chemistry education, (a) because it considers the diversity of interests, pre-knowledge, capabilities, and learning styles and (b) because it offers the students situations in which they can develop and apply competencies in all areas as demanded by the National Standards in Germany.

All teaching and learning units are structured by four phases: (1) phase of contact (aiming at the students' motivation and an activation of their pre-knowledge), (2) phase of curiosity and planning (aiming at the development of the students' questions and structuring the following learning process), (3) phase of development and presentation, and (4) phase of summary, deepening, exercise and abstraction, and transfer.

Opportunities for active learning of students are given in all four phases but with different meanings. In the first phase of contact, the students are expected to bring in their own ideas and questions into the discussion and further planning. To do this, the students have to connect the chosen topic with their pre-knowledge and daily-life experience, with is often a lack of competence already (see above). The second phase demands the students to decide on relevant questions which could be answered based on scientific inquiry (see Fig. 12.1). This competency is mentioned as one of the central goals in the definition of scientific literacy, according to the OECD-PISA-consortium: "Scientific literacy is the capacity: (1) to use scientific knowledge, (2) to identify questions, and (3) to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity." The students have to learn the characteristics of the specific "Nature of Science (NoS)" to differentiate between scientific questions, more detailed chemical questions, and others. Therefore, this approach also fosters the development of an understanding of the Nature of Science (Lederman 1992; McComas 2000). Of course, especially in the beginning of chemistry classes, the students will get exemplary questions which they could then use as analogies or "templates" for further units to choose and to define their own ideas and research questions.

The most student-oriented phase is the third one: In this phase of development, the students often work in groups. The teachers prepare learning environments that enable the students to carry out investigations according to their own interests, abilities, and time needed, for example by using the method of expert groups (Leerhoff et al. 2002). Another often applied method was the design of learning cycles or stations (Leerhoff et al. 2000): All students get a list of obligatory stations and additional stations which they have to work on. The sequence of stations can be free or given in advance. Usually, not all stations incorporate experiments to enable the teacher to observe the experimental stations in particular, while others do not need any specific observation and can be carried out by the students themselves.

The most open approach is the design of tasks which only describes a situation and for which the students have to develop their own methods of investigation, often experiments. The students enjoyed this creative work very much and the results were even better than the teachers had expected (Kandt 2008). Of course, this very open approach could not be used for every topic and in every situation, but the teachers were asked to incorporate it, if possible.

The last phase of summary and abstraction (see Fig. 12.1) is the most teacher-based one. Students often cannot decide themselves which aspects of a topic to be the most important ones, where to make connections to other contexts or how to deepen their understanding of basic concepts (such as the concept of matter and particles or energy). Therefore, as one result of the trials of CHiK, the teachers usually had to guide this phase and help the students to summary, to reflect and to "decontextualize" their knowledge.

Last but not least, the success of every teaching and learning unit does not only depend on the learning activities but also on the testing and reflecting of gained knowledge and competencies. The tests developed in *Chemie im Kontext* expected the students to be able to name and to apply basic concepts and factual knowledge as well as to create ideas for investigations, to translate daily-life situations (and language) into scientific questions (and language) and to evaluate decisions, as described in the definition of scientific literacy. The results overall were very satisfying: the students showed better or equal results in cognitive areas, appreciated the relevance of chemistry better and did not show the same dramatic loss of interest as reported in other chemistry classes (Demuth et al. 2008; Parchmann et al. 2006).

Active Learning for Teachers and Researchers: Learning Communities as "Catalysts"

CHiK was not developed as a complete curriculum, it was developed as a framework with exemplary units to enable teachers in different states and schools to adopt it to their syllabi and conditions (Parchmann et al. 2006). Hence, the implementation of CHiK was also part of the further development of teaching and learning units and material, based on the idea of "learning communities" (see Fig. 12.2). Such communities enabled a close cooperation between teachers in practice and university educators and researches, which assured the CHiK approach to consider the demands of research findings and school practise at the same time.

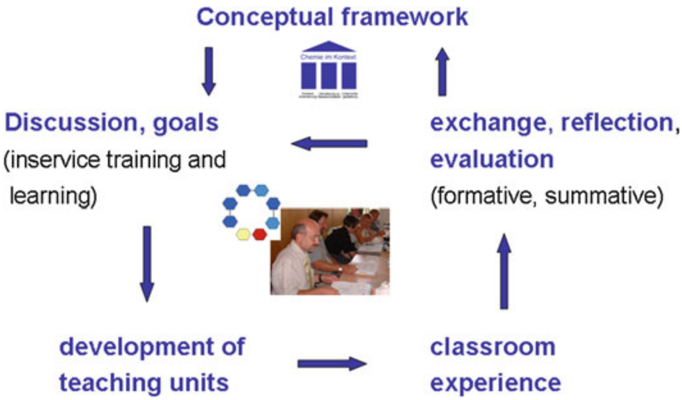

Fig. 12.2 Active learning of teachers and researchers in "symbiotic" learning communities

As such groups did not only carry out units and trial material but developed and designed their own ones, their learning can also be classified as active learning. The special situation of the close cooperation between different experts—teachers and researchers—led to an exchange of ideas, arguments, and expertise which does normally not happen in in-service training workshops, where the researchers are the "teachers" and the participants the "students." Looking at the results again, the teachers had not only enjoyed this work very much but also appreciated the worth of the learning communities to change and develop their teaching practise (Demuth et al. 2008; Parchmann et al. 2006).

CHEMOL

Active Learning for Students: Stories as Learning Catalysts

The CHEMOL-Project invites elementary school students to the chemistry laboratory for expanding their experimental abilities in learning environments focussed on science tasks. The teaching method that is mainly used is based on constructivistic ideas such as exploratory learning. The units, which are to acquire in CHEMOL, refer to four major topics: fire and combustion, water and solving, the gaseous state of matter and acids and bases. The learning setting is based upon students' preconceptions and is orientated toward their questions.

Active learning in CHEMOL means that students are confronted with tasks that they can survey because of the focusing upon one aspect, the possibility to develop own experiments and interpret the outcome together in a group. Additionally students expand their experimental abilities through real problem solving tasks.

One Example: Why Does a Candle Burn?

For the matter fire and combustion an approximately 20 experiments comprehensive environment replies to the question what a candle needs for burning. Students are confronted with wax/stearine as combustible material. Different burning materials are going to be investigated, too, and the state of matter also affects the interpretation of the experiment with wax. Students will be given several different tasks for describing the combustible material and classify them into different categories. The problem of temperature of ignition is very different to broach the issue in educational settings as it is not easy to show in experiments. To approach the problem, the students measure the temperature of different sources. They find out that even a candle compared to their own body temperature used as reference is much hotter—about 800 °C. The question why we can burn ourselves in a flame can be answered by this insight which can easily be achieved by elementary school students.

Inalienable and essential for students to gain the cognition of oxygen as needful for fire to burn is the conception of oxygen as invisible, gaseous matter. Therefore, students are brought to cognitive conflicts concerning first the missing air in experiments with fire covered with glasses. The task which brings the conflict lays in the question to save the fire of the candle just before it has been extinguished. The students learn to lift the glass a little bit so that air (oxygen) feeds the combustion and the flame is saved (see Fig. 12.3). By varying the variables in only one component, the students also learn a very essential idea of scientific experiences: varying only one variable at a time. Otherwise, the task will soon get too complex to be solved by elementary school students. Often different volumes of glasses are used to show the need of air or even oxygen as needful condition for combustible processes, but cognitive capacities of elementary school students are often overstrained coping with the variable of air and volume together.

In an investigation focussing on the subserving methods for elementary school students to gain insight of abstract ideas in science, the method of concept mapping is used for investigating effectiveness. The quantitative evaluation of used concepts shows impressively that special scientific terms such as oxygen, temperature, or combustible material are very important for effective learning processes (e.g., see Fig. 12.4). In the CHEMOL-project these terms are introduced additionally to the experimental work and inserted in established cognitive structures by using them in different situations and different contexts. The learning

Fig. 12.3 Saving flame by lifting glass

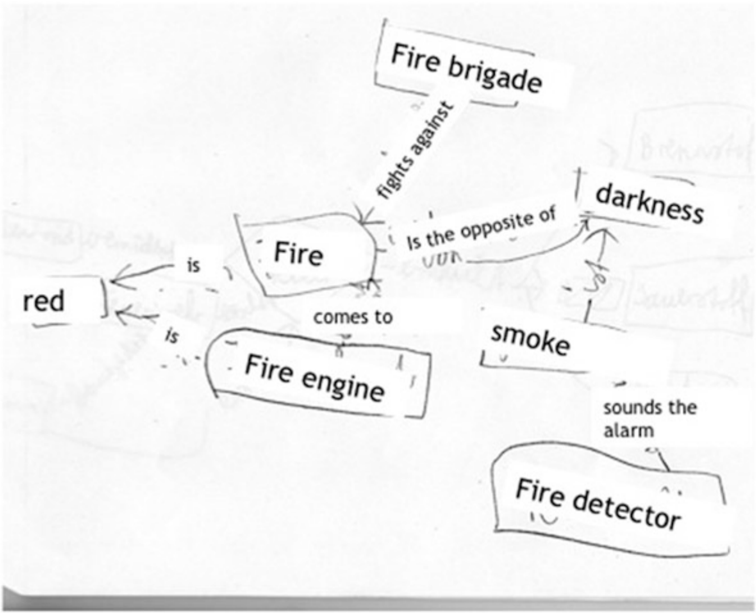

Fig. 12.4 Concept map

of these special terms builds up the cognitive structures for concepts of burning and combustion and works against rote learning by linking concepts. In an explicit way these linked concepts can be visualized by methods such as concept mapping. It can easily be used for diagnostic senses and promotes meaningful learning processes even for young learners.

For students in teacher training the "hands-on" activity in CHEMOL, where they structure educational topics for learners, and realize them with two or three children, is a very effective way to initialize "active learning" processes. The reflection of their own activity helps to overcome difficulties having regards to the educational structuration process as well as the teaching situation and fosters preparing them for their profession as a teacher (Steffensky and Parchmann 2007).

Outlook: "ProChem"—A Synthesis Between CHiK and CHEMOL with a Special Focus on the Problem of Transfer

The didactical approach of "Chemistry in context" puts the focus of the lessons in a thematic unit onto themes or problems of daily life, which are relevant and interesting for the learners. Such contexts motivate and structure what happens in the lessons in such a way that questions can be deduced and be answered during the process of finding conclusions by formulating specific topics. This didactical approach wants to fix scientific issues by their importance in the context and at the same time point out the transition of the conclusions concerning transfer. Here the last phase, the already characterized phase of summary, deepening, exercise, abstraction, and transfer, is in the focus. This fourth phase means the extraction of the acquired scientific concepts out of the context of the learning process and using them in new contexts afterward. Interviews with teachers concerning the qualitative rating of the facilitation of transfer in the didactical approach of "Chemistry in context" focused especially on the last phase, in which the teachers in common complained about the learners' ability to use learned scientific contents in new tasks. But also on the teacher's side one could say that neither mostly they weren't aware of the importance of the didactical approach's last phase, nor able to support transfer in the sense of a recontextualization. They had no ideas concerning the necessary basics of transfer as well as guidelines for a professional choice of suitable new contexts in a thematic unit.

Regarding the results of the interview study with the formulated central problems in the teaching process in the context-based approach of chemistry education, "ProChem" was developed on the basis of currently discussed transfer theories. "ProChem's" central objective target is the stronger emphasis on the idea of transfer in the learning process by using a variety of open problem situations in a specific scientific topic. Due to the contexts which demand near transfer as well as far transfer the scientific concept lying behind the thematic unit is steadily broadened and deepened. This is because of the analogies and regularities the problem situations point out so the learners are able to formulate generalizations. For half-a-year, the approach of "ProChem" for interfering scientific basic knowledge—in the sense of ideas and concepts—for elementary age has been in evaluation. The focus of this didactic direction of this approach is the embedding of particular chemistry contents in open problem situations, superordinated in a story, for which the arrangement of the experiments of the before described CHEMOL-project is important. The development of the scientific concept shows three phases which result directly out of the chosen contexts. Starting with a first phase to acquire the fundamental chemistry issues of a thematic unit, a second phase with a new context demands near transfer. Depending on the performance and previous knowledge of the learners, the first phase can be left out and a flexible start with the second one is possible. Of great importance is the third phase of each content, which demands far transfer and thus gives in insight into the learning process of the student and the state of knowledge. The exemplary teaching unit on the content of "air" described below concretely demonstrates the structure described above.

The heroes of the adventure story, which enable the students to get an emotional entrance into the learning process, want to salvage a treasure deep down at the bottom of the sea, but they are extremely afraid of water. This, being very motivating for kids in elementary school problem because of the immanent drama, results in the suggestion to use a diving bell. The simple experiment to explain the principal functionality of the diving bell contains a discovery that is astonishing for learners of this age: in the vessel used in this experiment isn't "nothing"—there is air in it. At this point they experience the material qualities of the invisible air. These properties are underlined as things developed in the story itself, where a hole in the diving bell leads to a lack of air. In a "rescue operation" air from one diving bell to the defect one is decanted. Now transfer is demanded in the directly following context, in which a supposedly genie in the bottle is presented to the students. The cold bottle, which is closed on the wet bottleneck with a five cent coin, is warmed up by the hands of the kids and the ghost in the bottle seems to speak through the hopping cent coin on the bottleneck. Near transfer is demanded in this case, since the learners have to recognize in analogy to the diving bell before, which is the existence of "air" in the bottle. The kids of this age in elementary school in our exemplary study groups had no problem to recognize the similarity to the context before and to transfer the knowledge and use it for explaining this new phenomenon. An enhancement represents the scientific approach of the expansion of air, when it is warmed up, which is responsible for the phenomenon of the "ghost in the bottle." The learners, personifying the air, which is typical for this age, realize the connection between the rise in temperature and the expansion of air very fast. This scientific issue is revived in a more complex context—the construction of a hot air balloon—at the end of the story. At this point of the teaching process, we observed a concrete reference to the experiment we described before, the "ghost in the bottle," in all our teaching experiments. The construction and the functionality of the balloon have caused no problems to the students in primary school, since they recognized the analogies and are able to formulate scientific laws.

To sum up, the teaching approach of "ProChem" uses the advantages of the approach of "chemistry in context" in case of the learning theory and the theory of motivation lying behind by emphasizing the ideas of transfer by using several contexts in the way of open problem situations which are staggered to support the ability of the learners to transfer their knowledge for solving relevant problems.

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