Journal of Innovation in Psychology, Education and Didactics	Vol. 20, No. 2 2016	163 - 188

THE IMPORTANCE OF BASIC EDUCATION IN SCIENCE: INTRODUCTION TO GERMAN SCIENCE CURRICULA AND THE IDEA OF “BASIC CONCEPTS”

CLAAS WEGNER [a], STEPHANIE OHLBERGER *[b]

[a, b] Bielefeld University, Germany

Abstract

Apart from mere subject-specific learning, pupils should be given the chance to acquire competences that they can also use independently from a topic or subject. In order to facilitate this ability, the German curricula have now been altered to teach pupils a wide variety of practical skills as well as how to reason on a scientific basis. The curricula contain both concept- and process-oriented competences, with basic concepts being classed among the contentual dimension of concept-oriented competences. They are topic-linking, superordinate rules and principles which connect different scientific phenomena. The article emphasises the competences’ importance and gives tips on how every teacher - even without national standards - can approach biology lessons in a new style.

Key words*:* basic concepts, biology, curriculum, scientific literacy

Introduction

Nowadays, school means far more than only passing on knowledge. Adolescents should be prepared for their future life and the vocational world which calls for the development of certain abilities and competences apart from being taught merely general and subject-specific knowledge. But where should this development be situated in school life? The new curricula in Germany put great emphasis on *competences* which are meant to integrate the learning of ways of thinking and working as well as social abilities into subject-learning. In the following, the construct of the *basic concepts* in the area of natural sciences will be described in further detail.

---

* Corresponding Author: Stephanie Ohlberger
E-mail address: stephanie.ohlberger@uni-bielefeld.de

Basic scientific education, scientific thinking and problem-solving are important prerequisites for participation in today's knowledge society. A general understanding of science and a critical evaluation of scientific developments helps one to become a responsible and mature person in a culture that is highly influenced by science.

Unsatisfying results of German students in the PISA (Baumert et al., 2001; Prenzel et al., 2004; Prenzel et al., 2007) and TIMSS (Martin et al., 2004; Mullis et al., 2005) studies call for an improvement of science classes within the context of scientific-propaedeutical teaching. Basic education in science is made up of the three competence constructs *epistemological views* (Hofer & Pintrich, 1997; Ledermann et al., 2002), *practical skills* and *scientific reasoning* (Kuhn et al., 1988; Klahr, 2000). The importance of these constructs is underlined by the fact that they are part of the process-oriented competences in the new curricula of Germany which focus on the *action ability* required in situations of scientific thinking and working. The decisive competence constructs are particularly present in the competence areas of *knowledge acquisition* and *evaluation*, dealing with experimental research methods, the usage of models and recognition, and the evaluation and assessment of subject-specific issues in different contexts. Accordingly, the existence of competence constructs in curricula shows how important those elements are for propaedeutical working and therefore also for the general quality of education. Discussions about the contents, means and places of mediation that pursue the objective of reinforcing basic education, led to the establishment of student laboratories and science centres at universities, research institutions and companies. This also applies to the project "Kolumbus-Kids" at Bielefeld University, an enrichment project for scientifically talented children. The project wants to convey the competence constructs mentioned above in an authentic learning environment by providing pupils with insights in natural scientific research and scientific methods. "Kolumbus-Kids" provides an excellent opportunity to observe and evaluate changes in performance over a longer period of time since pupils of different grades (4th-7th and 10th year) participate in the project for one year and can be observed throughout that time. The project also wants to help teachers by providing tips and recommendations for action and hence support them to impart those competences. In that respect it is important to point out which skills and abilities are crucial for the development of the core competences and which of them have to be brought across in particular, apart from generating interest and motivation in everyday teaching.

Theoretical Background and Possibilities of Implementation

Daily challenges in working and everyday life highlight the necessity of an extensive basic education in science. Also, recent developments in science and research call for people who can adjust to and cope with certain situations in life all the faster. Most people value science, admire the progress and are powerless in regard to its consequences (Wamek, 1985), yet they tend not to understand scientific processes in detail. Therefore it is necessary to establish a systematic and interconnected knowledge structure in school and promote the independent analysis of natural scientific principles with the help of appropriate learning strategies. Using these, it is also possible to foster central competence constructs like *epistemological views*, *scientific reasoning* and *practical skills.* Under the general orientation of science propaedeutics, the aims of modern education should always include the interconnection of general knowledge and science in order to bring up mature young adults. This implies that natural scientific competence is a vital prerequisite for participation in our today's knowledge society and for a life-long analysis of a changing world (German PISA Consortium, 2001).

Basic concepts in science teaching help to restrict the plenitude of content and to develop complex knowledge structures considering the abilities of every learner. However, it is not only the schools which are responsible for arousing interest in science. Depending on their different didactic-methodological and contentual focus, more and more extra-curricular institutions are committed to making scientific methods of knowledge acquisition accessible to pupils within the framework of student laboratories or science centres (Engeln & Rost, 2006). Certainly those institutions have the advantage of providing authentic learning environments, the possibility to introduce pupils to the latest scientific research and to experiment with real research objects, which shed light upon current research and which exceeds the resources of schools. Without adherence to a curriculum or time pressure, pupils can do research and try out methods as well as improve their skills and abilities in terms of scientific knowledge acquisition. This carries utmost importance for the understanding of scientific results and their evaluation (Carey & Smith, 1993; Kuhn et al., 1988). Extra-curricular programmes, such as "Kolumbus-Kids", are therefore able to influence central competence constructs in science education, their conveyance and training. Still, evidence of the scope and manner of how those competences should be mediated is missing and it is also unclear to what extent extra-curricular institutions and their scientific propaedeutic teaching improve natural scientific competences.

Basic Concepts in Biology Teaching

German schools were to face tremendous changes in the last few years. Keywords like PISA, centralised A-levels (*Abitur*) and the shortening of schooling to 12 years (G8) are matters of general concern. This also resulted in changes in biology teaching, where contents and criteria of the curriculum had to be adjusted to the new scholastic standards and consistent examination requirements. The drawback of a standardised school system is that pupils now feel insecure as they have to pass comparison tests and centralised A-levels. This raises the question of how the educational content can be treated in such a way that pupils are sufficiently prepared for the exams, or in other words: how can the plenitude of content be structured in order for the pupils to retrieve and apply it easily in new contexts?

As stated above, there have been alterations in terms of educational policy that led to the revision of curricula. For the subject of biology, the following priorities were set:

- Factual knowledge should not be acquired in isolated contexts. The pupils should rather gain an overall view of biological phenomena which goes hand in hand with the creation of a systematic and interconnected knowledge structure (Beyer, 2008, p. 16).
- Pupils should be equipped with the ability to understand biological principles on their own by supplying them with learning strategies (important for integrating new knowledge into already existing cognitive structures, Friedrich & Mandl, 2006, p. 2).
- Elaboration strategies are to be trained. This includes analogy formation and effective note taking in order to improve learning success.

For the purpose of cutting down the amount of content that has to be treated within the sciences, the federal state of North Rhine-Westphalia enforced the plan of the *basic concepts*. The basic concepts are parts of contentual concepts and themes that are fundamental and circumscribed for the purpose of teaching in order to make them understandable for pupils (Sommer, 2008, p. 12). Further, the basic concepts include principles and theories of all three science subjects, namely Biology, Physics and Chemistry. Evolving around a specific learning method, learning is understood as an active process in which the teacher offers support to the pupils and acts as a facilitator only. Due to preparation and intense engagement with the subject content, the teacher is aware of the meaningfulness and structure of that particular knowledge. The difficulty, however, is to bring that meaningfulness home to the pupils in order for them to develop a systematic knowledge structure. This is why it seems to be necessary not only to focus on subject-specific issues, but also to take into account the conveyance of competences that fit into the context of basic education in science (also called *Scientific Literacy*). According to Gräber's triadic model, *Scientific Literacy* is made up of the main components *knowledge*, *evaluation* and *action* (see figure 1).

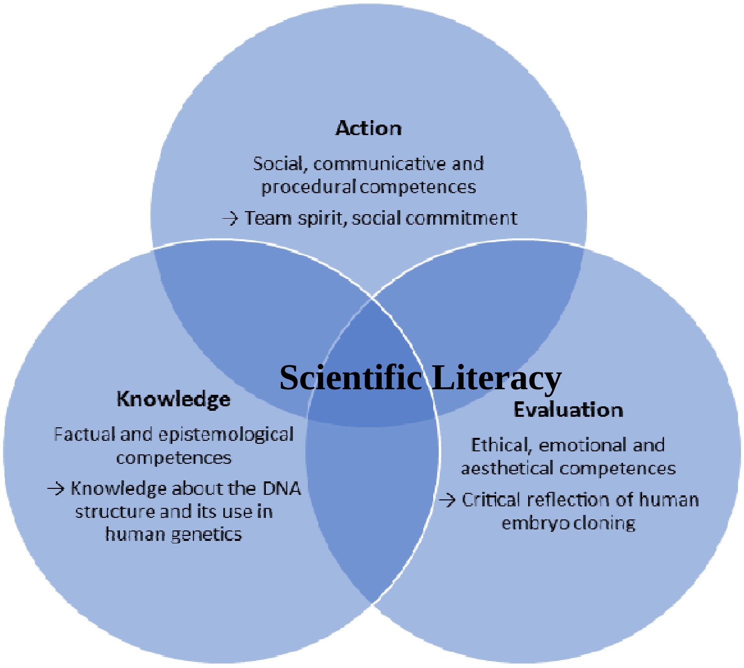


Figure 1. The model of “Scientific Literacy” based on Gräber (2002)

The model describes a scientific understanding of the environment (*knowledge*) and thus includes appropriate *action* and *evaluation*. The overlap of those three components forms the *Scientific Literacy*, which pupils are supposed to acquire in order to be able to gain a profound scientific education. Within the area of *knowledge*, factual and epistemological competences are integrated. An example for that would be learning about the structure of DNA as well as its scientific employment in human genetics. Pupils should also be able to make ethical, emotional and aesthetic judgments (*evaluation*). This knowledge could be the basis for a deeper discussion for instance about cloning of human embryos and hence has relation to their surrounding world and future life. In the context of *action,* it is desirable to foster social, communicative and procedural competences. What this all amounts to is that the acquisition of such diverse knowledge enables pupils to participate in and actively shape our society which has come to be increasingly influenced by the natural sciences.

Lichtner (2007) emphasises the fact that the gradual increase of those competences are the central element of cumulative learning. Pupils in year 5, for example, get to know about the construction of a plant and the functions of the organelles before they can understand the transport of water and nutrients in xylem and phloem as well as photosynthesis at the end of sixth form in grammar schools (*gymnasiale Oberstufe*) (see figure 2).

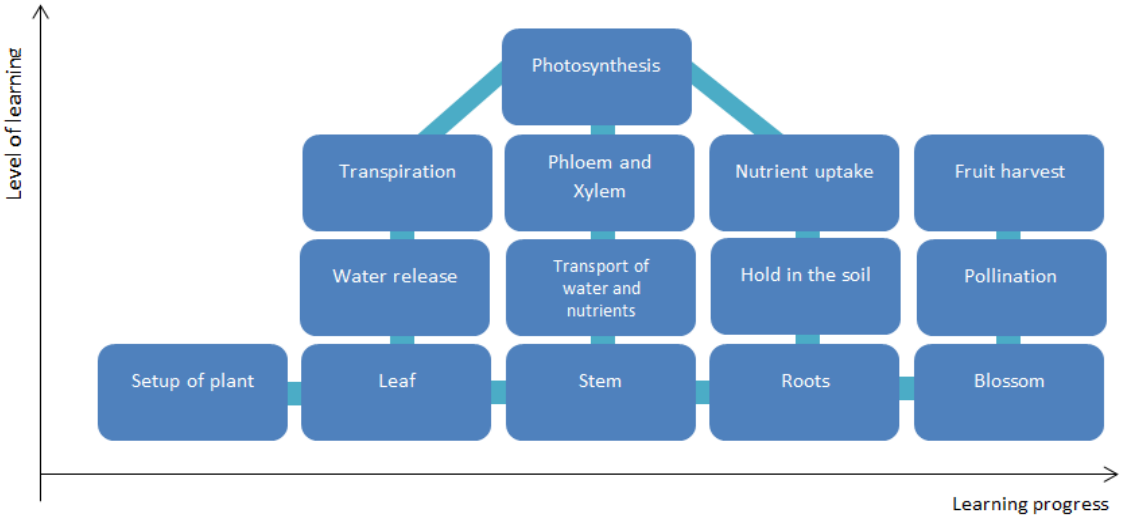


Figure 2. The concept of cumulative learning illustrated with examples of Biology

Cumulative learning thus allows for a better implementation of the educational content into the living environment. Opposed to that, there is the concept of additive learning. An example for that would be learning about the construction of animal cells without providing thematic parallels to plant cells. This could lead to misinterpretations of why certain organelles are not present in the other cell type and possibly look for cell walls and vacuoles in animal cells (see figure 3).

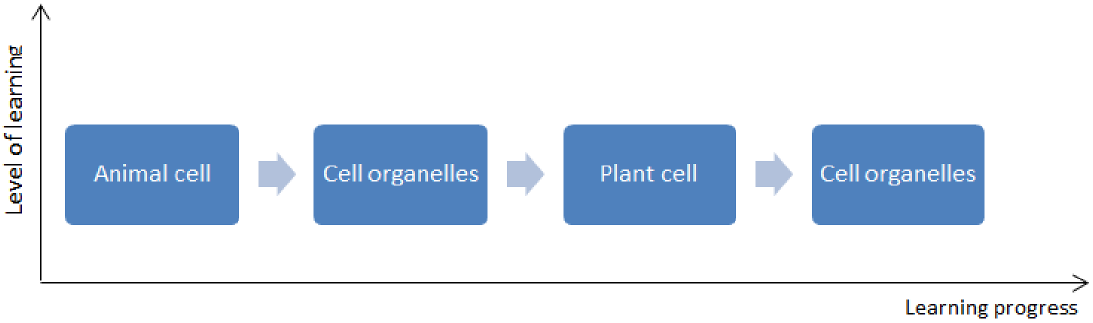


Figure 3. The concept of additive learning illustrated with examples from Biology

Furthermore, emphasis is put on building a complex knowledge structure with the focus on the learning progress and the application of knowledge as *meaningful learning*. This implies a focus on the learner’s abilities and topic-connecting basic concepts which are integrated into teaching. Due to that, pupils are able to rediscover biological principles and phenomena in new subject areas. It is easier for them to create links to new topics and highlight important connections, particularly with regard to exams. The interconnected ways of thinking on behalf of the students can also be an advantage for the teacher.

The Notion of Basic Concepts

In the last few years, the scholastic standards of the individual counties in Germany set new curricula considering the shortening of the secondary school career from nine to eight years. The new syllabi are called *competence-oriented* which implies that pupils should have acquired certain competences after secondary school level I (year 9) in order to meet the requirements of secondary school level II (Sixth Form, *Oberstufe*). In the subject of Biology, the competences which account for basic education in science can be divided into two areas:

- *Concept-oriented competences* embrace the contentual dimension of the subject matter and foster biological knowledge which underlie the basic concepts. An example would be the construction of animal and plant cells and the relation of form and function which has to be imparted gradually to the pupils.
- *Process-oriented competences* are based on affective learning objectives and describe action processes which are to be acquired by the pupils. In the natural sciences, these are specific ways of thinking and working skills like the step-by-step planning of an experiment and pupils’ introduction to a scientific instrument such as the microscope (and how to draw slide preparations).

As mentioned in the description of concept-oriented competences, basic concepts are classed among the contentual dimension in lesson planning. They are topic-linking, superordinate rules and principles which link different scientific phenomena. Further, they present a shortened version of subject-specific concepts, which help to structure the multitudinous plenitude of content and therefore can be understood more easily by the pupils. The acquisition of competences is crucial in all three science subjects at school, which is why also physics and chemistry have basic concepts as superordinate structures (see table 1).

Table 1: Arrangement of basic concepts in the subjects of Biology, Chemistry and Physics.

	Basic concepts			
Biology	System	Structure and function	Development	
Chemistry	Chemical reaction	Structure of matter	Energy	
Physics	System	Structure of matter	Energy	Interactions

The biological content is divided into the perspectives of (1) system, (2) structure and function and (3) development. With regard to all three sciences, there are substantial overlaps in the basic concepts due to a similar perception of the terms. This, in turn, enables synergy effects to be used by teachers and learners in order to interconnect knowledge structures.

All subjects examine the structure of matter (Physics and Chemistry) and of plants and beings (Biology) and their function, since knowledge about the characteristics, composition, modifications and origin of substances supports understanding. As the concept of development can only be approached in living nature, it is incorporated in Biology teaching. Even though the concept of energy is not listed in biology, it is nonetheless of crucial interest in that subject, as “living systems are characterised as open systems on the basis of exchanging substances and energy” (Core Curriculum for Biology North Rhine-Westphalia, 2008, p. 26). Consequently, the concept is evident in fields such as construction and performance of the human body or energy flow and metabolic cycles in ecosystems.

So, obviously, basic concepts facilitate learning about subject-specific content. Teachers can extract certain competences that they want to stress in relation to biological phenomena and which could be helpful for understanding the wider context. Even more important are the basic concepts for learners as they foster the development of a knowledge network, allowing for the re-discovery of biological main concepts in various examples (see example 1).

Example 1: The discussion could be about adaptations of the mole with regard to its underground habitat and, connected to that, the evolution of hands which are suitable for digging. This example will first introduce the basic concept of structure and function and later be picked up on again in the context of evolution and homologies and analogies.

Example 2: Pupils observe how mice deal with stressful situations in the open field and note down their routes. This practical work prevents the occurrence of "inert" knowledge (i.e. knowledge structures that have been acquired but cannot be used in other contexts and therefore fail in being stored in the long-term memory).

Basic concepts also promote subject-specific competences. Pupils are encouraged to observe and describe biological phenomena in detail under consideration of their peculiarities (see example 2).

Apart from the division of the basic concepts in Biology into three broad areas (structure and function, system, and development), these can be broken down into further main principles, such as variability and conformism, energy and substance conversion, regulation and control, information and communication as well as phylogeny and affinity. Due to subject-specific relations among all science subjects, basic concepts are also useful in the learning progress itself inasmuch as they structure and interconnect the content. New experiences and insights can be linked to already existing knowledge even quicker and the basic concepts will be picked up and adjusted over and over again. By that diverse knowledge connections are established and hence equip pupils to consider content from different perspectives.

Crucial for the pupils' development is the distinction of concept-oriented and process-oriented competences since biological working skills are as important as subject-specific knowledge. After having focused on concept-oriented competences so far, attention will be shifted to process-oriented competences which particularly encompass methodological aspects. This involves scientific ways of thinking and working and is further subdivided into *knowledge acquisition*, *evaluation* and *communication*. Firstly, *knowledge acquisition* contains subject-specific methods, especially fundamental structures of the Scientific Method (phenomenon – hypothesis formation – experimental investigation – falsification of hypotheses and induction/deduction). Also, working with models belongs to this category, which is integrated in the curriculum's description as "pupils observe and describe biological phenomena and processes and distinguish between observation and explanation" (Core Curriculum for Biology North Rhine-Westphalia 2008). Secondly, *evaluation* comprises the detection of biological issues in different contexts and their conclusive evaluation (e.g. "pupils assess measures and behaviours for the conservation of their own health and social responsibility", Core Curriculum for Biology North Rhine-Westphalia, 2008). Thirdly, *communication* can be looked at from an interdisciplinary point of view since the exchange and analysis of information is crucial in this field of competence (e.g. "pupils plan, communicate and reflect their work, also as a team", Core Curriculum for Biology North Rhine-Westphalia, 2008).

According to the curriculum of North Rhine-Westphalia, the areas of competences as mentioned above are binding standards for the subject of Biology and describe knowledge, skills and abilities that are to be achieved cumulatively by 9th grade. The competences are expected to be a result of the learning as such and should not be treated as individual topics. Equally relevant for pupils is the development of personal and social competences, which enable life-long learning and participation in society. Therefore, pupils should learn to bear responsibility for their learning process, employ learning strategies consciously and explore biological phenomena with others.

The only question remaining is how the basic concepts can be conveyed best. On top of everything, teaching units should centre on meaningful, real world contexts. Further, pupils can understand the teaching design better once the approach is phenomenon-, context- and problem-oriented and exemplary, which enables them to find links and comparative references. Perhaps the most difficult aspect is to bridge the time of learning and retrieval. Two solutions are suggested to that problem. Either previous content can be repeated with the help of a worksheet in which pupils have to compare known facts with new example cases or teachers might use market place learning. Different examples of the same basic concept can be dealt with at different stations organised in the classroom and the pupils have to explain similarities and differences of seemingly incoherent examples. This trains the ability to transfer knowledge of a well-known case to new contexts.

Within the project “Kolumbus-Kids” (for more information on the project, please visit *www.kolumbus-kids.de* or see Wegner & Minnaert, 2012; Wegner et al., 2013) children are motivated to explore their environment and particularly biological phenomena. With respect to the basic concepts, the project staff tries to highlight links between biological topics. In the field of bionics, the lotus effect can be taken as an example. It could be focused on its benefits for technology and nature, or on the developmental advantages for plants in contrast to other conspecifics and the systematic requirements, such as a thickened cuticle, could be presented in a holistic, interconnected context. Such an implementation works best if children can deal with the research topic in an action- and problem-oriented way. This is exactly why participants in the project have the opportunity to develop their own ideas and investigate in a team with other children.

Scientific Propaedeutics

In order for the pupils to be taught successfully according to the principles just mentioned, some preconditions have to be met. But what exactly is science propaedeutics and why is it important in biology teaching? Contents and competences of natural scientific knowledge acquisition are the most essential part of scientific education, internationally known as *Scientific Inquiry* and *Nature of Science*. Within the scholastic context, pupils are expected to learn how one obtains scientific findings and how natural scientific methods and statements are characterised. Scientific education within the broader context of social participation is entitled *Scientific Literacy* (see chapter 3) in the German-speaking area. According to the OECD (Organisation for Economic Co-operation and Development), *Scientific Literacy* in PISA is defined as "the capacity to use scientific knowledge, to identify questions and 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" (OECD, 1999, p. 76).

By means of this ability, access to society and possibilities of participation in current events are created since the main features of the natural world and anthropological interventions can be understood. With respect to the demands of the Education Council and the recommendations of the conference of ministers for the arts and culture, scientific-propaedeutical teaching implies more than just introducing scientific ways of thinking and working. To an even greater extent, the understanding of collaboration and coherence of the sciences should be fostered and the limitations of scientific statements should be accentuated (Falkenhausen & Vollmer, 1985, p. 10). In doing so, epistemological and philosophical issues are dealt with in science lessons.

Figure 4 shows how the three central dimensions build the framework of the competence area of knowledge acquisition which is *the* feature of scientific-propaedeutical teaching. This implies the *nature of science, scientific inquiry* and *practical work.* With the help of the cognitive psychological constructs *epistemological views, scientific reasoning* and *practical skills*, the three dimensions mentioned before, can be correlated in a systematic way (see figure 4).

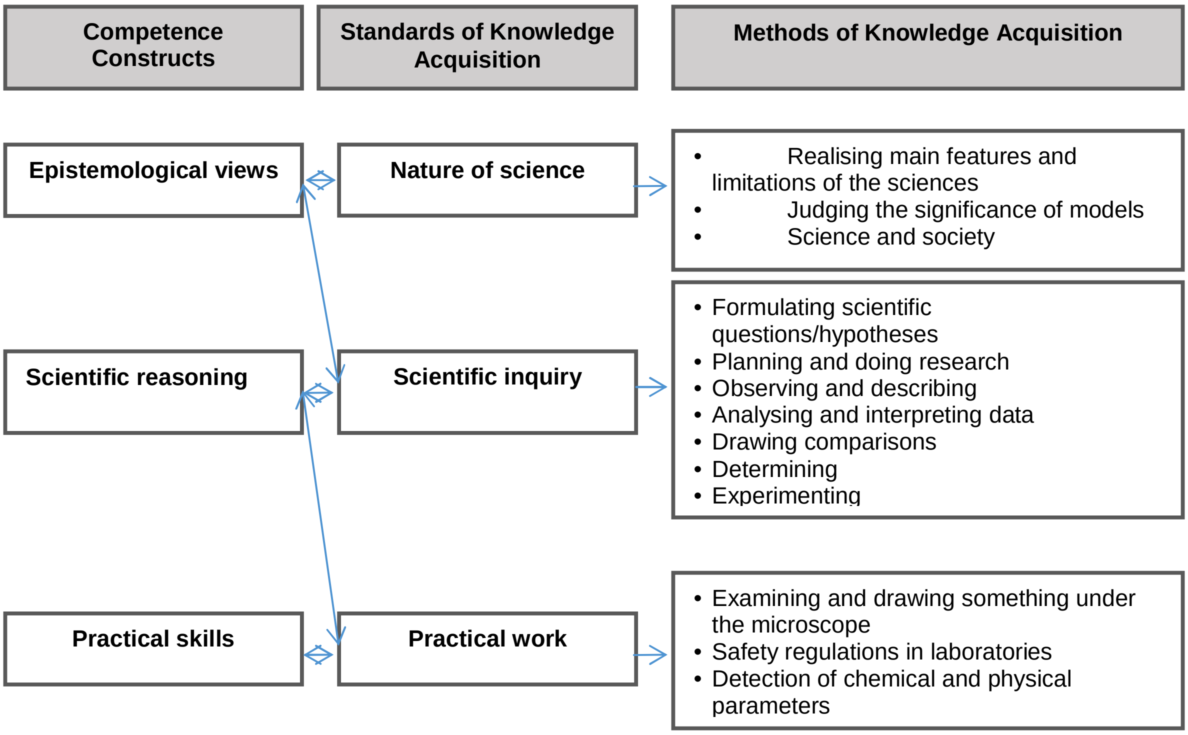
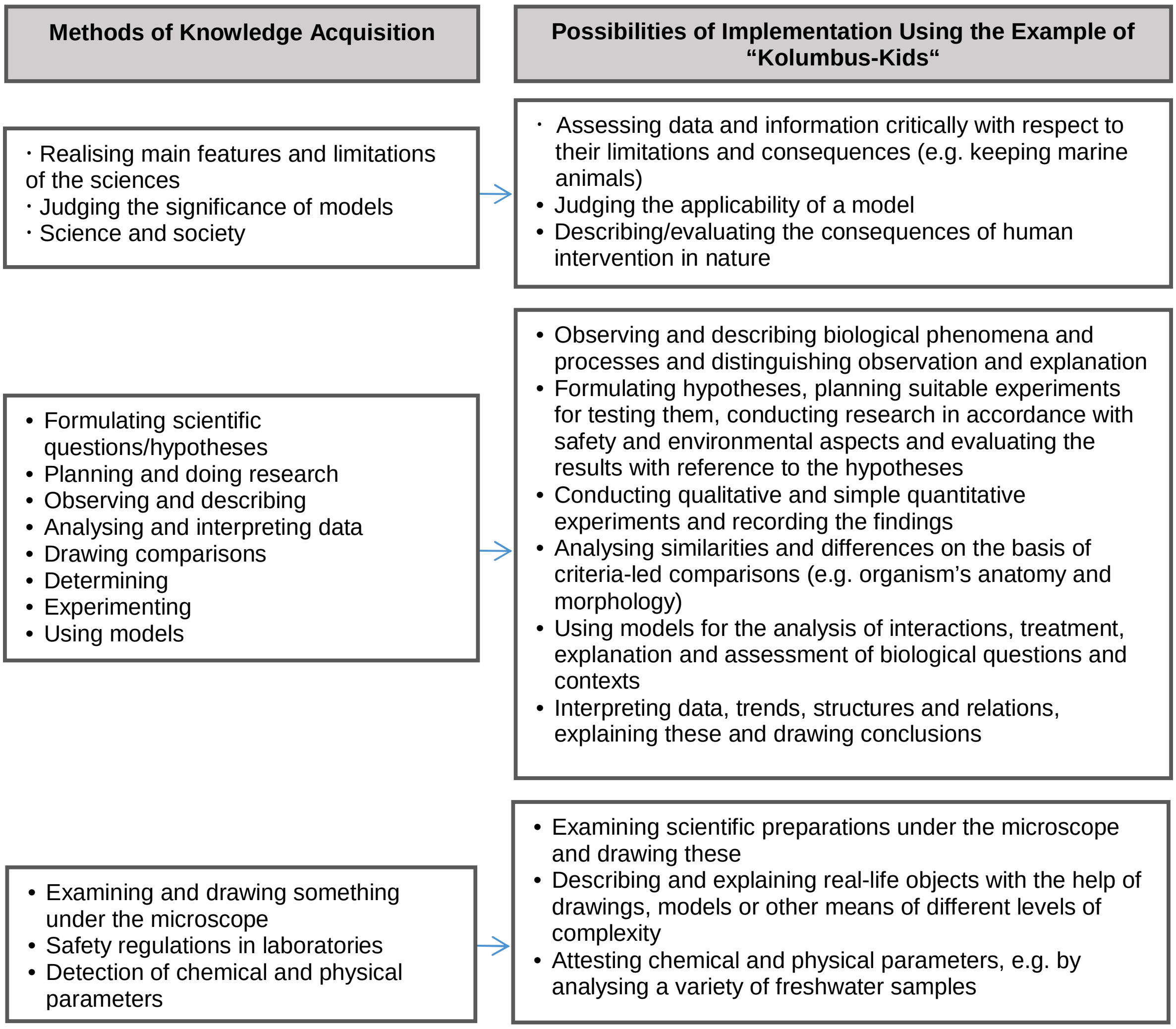


Figure 4. Framework of the competence constructs (based on Mayer, 2007). The standardised competence constructs are the skills and abilities that comprise ways of how something is done in order to achieve a certain goal.

It becomes apparent that the *nature of science* comprises features and limitations of the sciences, judging by the significance of models and society and science. Only by knowing about the common features and limitations of science, by estimating the significance of models and by recognising the relationship between society and science, a comprehensive understanding of science can be achieved. Those epistemological views again interact with scientific inquiry. In order to acknowledge features and limitations of science, one has to conduct and analyse research and interpret the importance, informative content and consequences of the findings. People first have to be acquainted with practical work in the sciences before they can be attested scientific reasoning. This, however, also implies practical skills which should be developed on the basis of scientific methods and techniques such as examining or measuring something under the microscope. Figure 5 provides an overview of methods of knowledge acquisition and how they are employed in the extra-curricular project “Kolumbus-Kids” at Bielefeld University.



Methods of Knowledge Acquisition	Possibilities of Implementation Using the Example of “Kolumbus-Kids“
· Realising main features and limitations of the sciences · Judging the significance of models · Science and society	· Assessing data and information critically with respect to their limitations and consequences (e.g. keeping marine animals) • Judging the applicability of a model • Describing/evaluating the consequences of human intervention in nature
• Formulating scientific questions/hypotheses • Planning and doing research • Observing and describing • Analysing and interpreting data • Drawing comparisons • Determining • Experimenting • Using models	• Observing and describing biological phenomena and processes and distinguishing observation and explanation • Formulating hypotheses, planning suitable experiments for testing them, conducting research in accordance with safety and environmental aspects and evaluating the results with reference to the hypotheses • Conducting qualitative and simple quantitative experiments and recording the findings • Analysing similarities and differences on the basis of criteria-led comparisons (e.g. organism’s anatomy and morphology) • Using models for the analysis of interactions, treatment, explanation and assessment of biological questions and contexts • Interpreting data, trends, structures and relations, explaining these and drawing conclusions
• Examining and drawing something under the microscope • Safety regulations in laboratories • Detection of chemical and physical parameters	• Examining scientific preparations under the microscope and drawing these • Describing and explaining real-life objects with the help of drawings, models or other means of different levels of complexity • Attesting chemical and physical parameters, e.g. by analysing a variety of freshwater samples

Figure 5. Possibilities of implementation using the example of “Kolumbus-Kids”

As figure 5 puts forward, there are various possibilities to implement the procedure of knowledge acquisition and problem-solving in any kind of scientific-propaedeutical teaching. One topic could be the relationship of science and society, exemplified by human influence on nature, or scientific observations based on criteria-led comparisons, e.g. in the context of organism’s anatomy and morphology. The options of implementation are orientated towards the biology curriculum of grades five to nine at grammar schools in the German federal state North Rhine-Westphalia. Within the three competence constructs (epistemological views, scientific reasoning and practical skills), the main focus is on scientific thinking, which eventually regards the process of scientific work as a process of problem-solving (Mayer et al., as cited in Mayer, 2007, p. 177). This is considered to be the most important element of scientific-propaedeutical teaching. In order to convey and train those competence constructs in regular schools, recommendations for action are listed below.

Tips for teachers:

- Observe, describe and compare biological phenomena.
- Conduct identification exercises.
- Together with your pupils formulate scientific questions and hypotheses.
- Train the pupils in methods of scientific working, such as microscoping, drawing and measuring.
- Plan appropriate investigations, conduct them and evaluate the results with your pupils.
- Discuss the informative content and the scope of scientific findings and illustrate the limitations of scientific research.
- Address the relationship of science and society.
- Use vivid/descriptive models for the purpose of knowledge acquisition.

Problem-Solving in Science

Problem-solving can be understood as overcoming a discrepancy between an initial state and a final state with the help of logical operators (Dörner, 1979; Funke, 2003 as cited in Mayer, 2007, p. 178). The concept comprises goal-oriented thinking and acting which is not accomplished via practised procedures (Mayer, 2007) but which is actually based on the application of knowledge and abilities in certain situations (Mayer, 2007). With regard to the framework of scientific competences as they have been presented in the previous part (Scientific Propaedeutics), this implies that by means of scientific inquiries, such as knowledge acquisition based on experiments, the final state can be reached when scientific reasoning obviously takes place. In the course of this, it is important to be able to recognise scientific questions and draw conclusions in order to understand and make decisions. In the case of experiments, going from the initial to the final state of problem-solving entails formulating hypotheses, planning and conducting experiments, interpreting test results and revising hypotheses. In the project “Kolumbus-Kids”, many ways of working depicted in figure 5 are used. In order to initiate problem-solving and thereby scientific-propaedeutical working, the pupils in the project are presented with the essential questions of the topic in a comprehensible form (see figure 6).

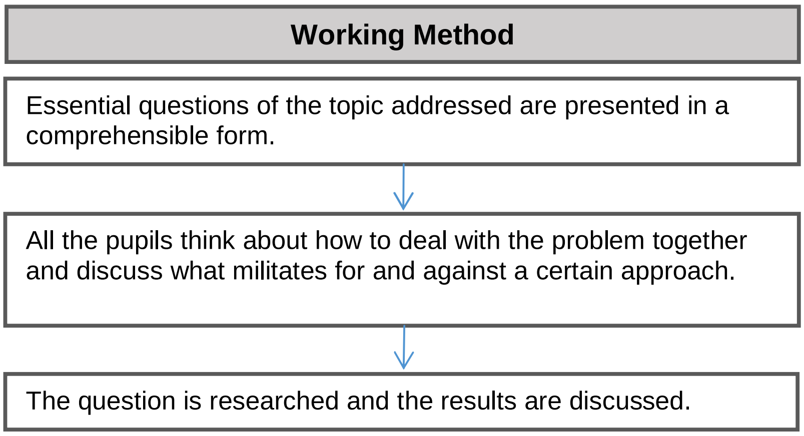


Figure 6. Working methods in the project “Kolumbus-Kids“

Care has to be taken that the questions are embedded in the superordinate biological context, meaning that the topic has to be really worth researching. Groups of pupils that think and act in a goal-oriented manner can overcome the gap between the question (initial state) and the result (final state). The application of knowledge and other required abilities help to research the problem and lay the foundation of the discussion of the results. Funke (2003 and 2006) gives an overview of empirical findings of problem-solving research. In this regard, three relevant features could be found to attribute to one’s problem-solving performance, namely *features of the problem*, *features of the person* and the *problem-solving situation* (see figure 7).

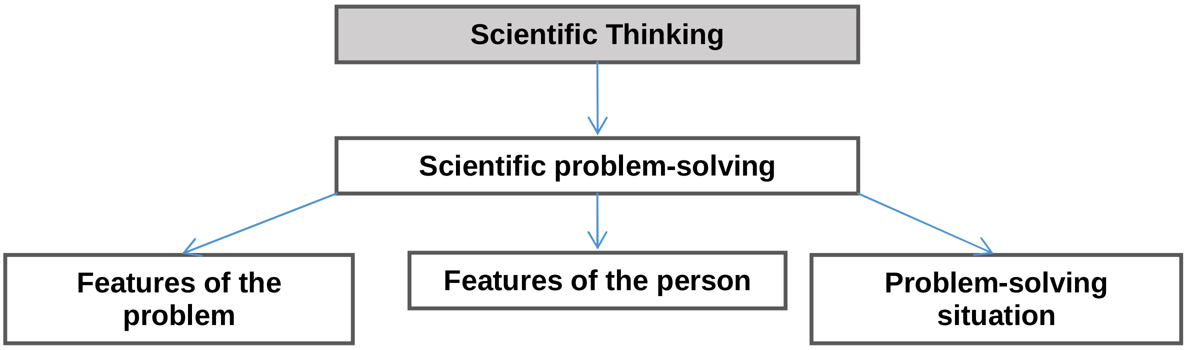


Figure 7. Relevant features for the performance in problem-solving. Scientific problem-solving and the corresponding features as characteristics of scientific thinking.

In order to go further into this issue, the next part concentrates on the lowest level of the illustration above, namely the features of the problem.

Features of the problem

In the context of scientific problem-solving and scientific-propaedeutical working, problems can be characterised from the starting point, the aim and the employment of resources. Mayer (2007) further distinguishes between

- well or badly defined problems (degree of the initial and target state's definiteness)
- cross-functional and domain-specific problems (interdisciplinary) and
- problem areas requiring poor or extensive knowledge (degree of required knowledge; e.g. mathematic, complex or scientific problem-solving) (Mayer, 2007, p. 179).

In order to finally solve the problem and overcome the initial state, the problem-solver has to meet certain requirements depending on the procedures and operations used for the process (Mayer, 2007, p. 179). This implies above all skills and abilities in the area of basic science education, meaning the ability to apply natural scientific knowledge, to recognise scientific questions and to draw conclusions in order to understand and make decisions. Causal thinking or induction and deduction are only some examples for those procedures. According to Funke (2006), the problem-solving process always follows a systematic sequence as it is illustrated in figure 8. For means of comparison, the method of operation in the "Kolumbus-Kids" project is displayed as well.

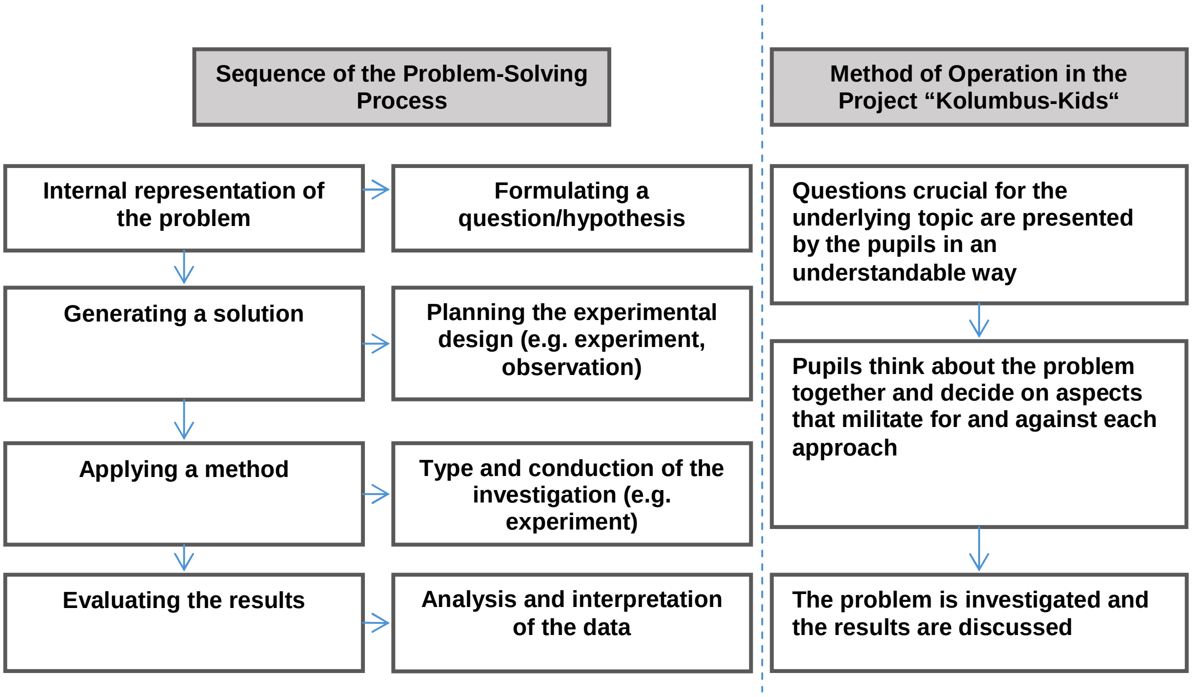


Figure 8. Systematic sequence of the problem-solving process.

As displayed in figure 8, Funke reasons that an internal representation of the problem is generated before a solution plan is developed. A certain method is then applied to solve the problem and the results gained in that process are evaluated. In more detail, this comprises the formulation of a hypothesis, the planning and carrying out of an experimental design which is then completed by the interpretation of the obtained data. A similar sequence can be found in the project “Kolumbus-Kids”. However, special emphasis is put on embedding the problems and questions into a superordinate biological context and encouraging joint reflection. It is exactly that amount of reflection which distinguishes scientific-propaedeutical teaching from the common, scientific-oriented classes. Apart from the procedures and operations needed for solving a problem, it is also the semantic context that is important. Studies by Stark et al. (1995) found that the implementation of complex and realistic scenarios into the presentation of the problem facilitates the application of what was learned in everyday life, particularly if the contexts vary (Stark et al., 1995 as cited in Mayer, 2007, p. 179). Pupils who notice references to their own lives therefore learn easier. This is why the problem should be introduced by raising questions that are of personal relevance to the pupils. Embedding the problem into a biological context consequently increases the likelihood that pupils will be interested in the subject since they are aware of its topicality and importance. Hereby, application of the content into everyday life will be accomplished much easier. Additionally, the traits of a person play a considerable role in the process of problem-solving. Providing everyday references and understanding the learner’s perspective has an enormous impact on functional clarification and thus on problem-solving.

Features of the person

According to Mayer (2007), a person’s features determine the quality of the problem treatment, which include: *declarative* and *procedural knowledge*, *meta-cognition* and *cognitive skills* (Mayer, 2007, p. 179). Whereas *declarative knowledge* means verbally expressible, conscious and factual existent concept knowledge, *procedural knowledge* regards automated, retrievable knowledge that can be put to practical use. The term declarative knowledge subsumes knowledge content that was learned by heart, such as memorising chemical formulae. This content can be transformed into declarative statements. As opposed to this, procedural knowledge encompasses strategies for problem-solving as well as automated patterns and methods for applying knowledge, such as making use of learned actions and (motor) abilities unconsciously. Also repetitive activities during the conduction of an experiment can be counted among this kind of knowledge. Pupils in the project “Kolumbus-Kids” encounter those courses of action regularly and are firmly established in their procedural knowledge so that the pupils do not have to think about every individual step when using their motor skills. Activities falling in this category can hardly be described in declarative statements.

Both forms, however, are part of long-term knowledge. Meta-cognition, on the other hand, describes the engagement with one's own cognitive processes, such as thoughts and opinions. Therefore, meta-cognitive knowledge enables a better understanding and control of the learning process. According to the PISA-consortium, meta-cognitive strategies are of higher order and can be employed by learners purposefully. They say that an important characteristic of self-regulated learning is the ability to select, combine and coordinate learning strategies. This also implies planning (e.g. the learning goal and the ways to achieve it), monitoring (e.g. the learning progress), controlling (e.g. changing the means) and evaluating (analysing the goal's attainment). (German PISA Consortium, 2000, p. 272).

Whereas meta-cognitive knowledge means knowledge about knowledge, cognitive abilities usually equal intelligence (Mayer, 2007, p. 179). So in order to handle a question appropriately, one has not only to consider the procedures applied in this context, but also the cognitive requirements and skills of a person. This and also the ability to reflect, is especially important in the context of scientific-propaedeutical thinking since knowledge acquisition is a very complex, cognitive and knowledge-based problem-solving process. Apart from the personal traits just presented, the special features of a situation play a further role.

Features of the situation

According to Funke (2003), *features of the situation* include, for example, the way of posing a question, presenting information (numbers, graphics, text) and solving problems individually or in a group (Funke, 2003 as cited in Mayer, 2007, p. 180). Klieme et al. (2005) found in various studies that the presentation of information rates very high (Klieme et al., 2005 as cited in Mayer, 2007, p. 180). This is why "Kolumbus-Kids" puts special emphasis on active, pupil-oriented learning in the context of different action-, social- and learning forms. The huge variety of topics such as marine biology, bionics, carnivorous plants and microbiology provide great opportunities to employ different methods and forms of learning. Next to focused single and partner work in experimental situations, e.g. measuring chemical parameters in a saltwater aquarium or working with a notebook for creating a poster on the topic "dairy products and microbiology", the pupils also think of appropriate test plants and experiments for investigating the lotus effect, and also conduct them (bionics). Due to the variety of the different topics and the change of action and social forms, the teaching concepts are not monotonous and furthermore provide the individual preferences and abilities of the pupils since they are continuously presented with new forms of learning, acting and working on their own or in a group. As Okada & Simon (1995) and Kunter et al. (2003) could show in their studies, problem-solving is more successful in groups than done individually (Okada & Simon, 1995; Kunter et al., 2003 as cited in Mayer, 2007, p. 180). Groups certainly have an advantage in exploratory activities (e.g. hypotheses, implementing new ideas or justifications) (Okada & Simon, 1995, p. 340). So, if possible, group work should be chosen over individual work. “Kolumbus-Kids” takes this finding into account and promotes team work and group identity through the use of suitable social forms. By this, the responsibility for oneself and the whole team is generated and revived. In the project, groups of three pupils at the maximum have been found to work best. More group members, however, create the opportunity for individuals to withdraw from activity. Even though not all academic discussions favour group work, the method still seems promising in the light of the studies of Okada & Simon (1995) and Kunter et al. (2003). Particularly with regard to scientific-propaedeutical working, which is made up of learning through exploration to a great extent, this seems very important. We shall further give some concrete recommendations for action.

Tips for teachers:

- Present essential questions based on the topic in an understandable way.
- Embed the questions in a superordinate biological context.
- Make use of complex, realistic and current scenarios that are close to the pupils’ everyday life, which are then integrated into the problem.
- Choose interdisciplinary and well-defined problems that request a certain degree of knowledge.
- Together with your pupils, think about the treatment of the problem and cooperatively agree on methods of action.
- Train your pupils in drawing conclusions from pieces of evidence.
- Always encourage pupils to exchange their thoughts.
- Reflect on the preliminary findings and revise the hypotheses that were formulated at the beginning.

- Vary your teaching with regard to topic diversity, presentation of information (numbers, graphs, text) and action and social forms.
- Let the pupils work on problem-solving tasks in groups.
- Coach the pupils in choosing, combining and coordinating the suitable learning strategies independently.

Problem-solving in science classes

As the process of natural scientific knowledge acquisition includes problem-solving to a large extent, it can be noted that the process is indeed relatively complex and cognitively demanding, a process further characterised by specific procedures (Mayer, 2007, p. 181). Its connection to science classes is explained in figure 9.

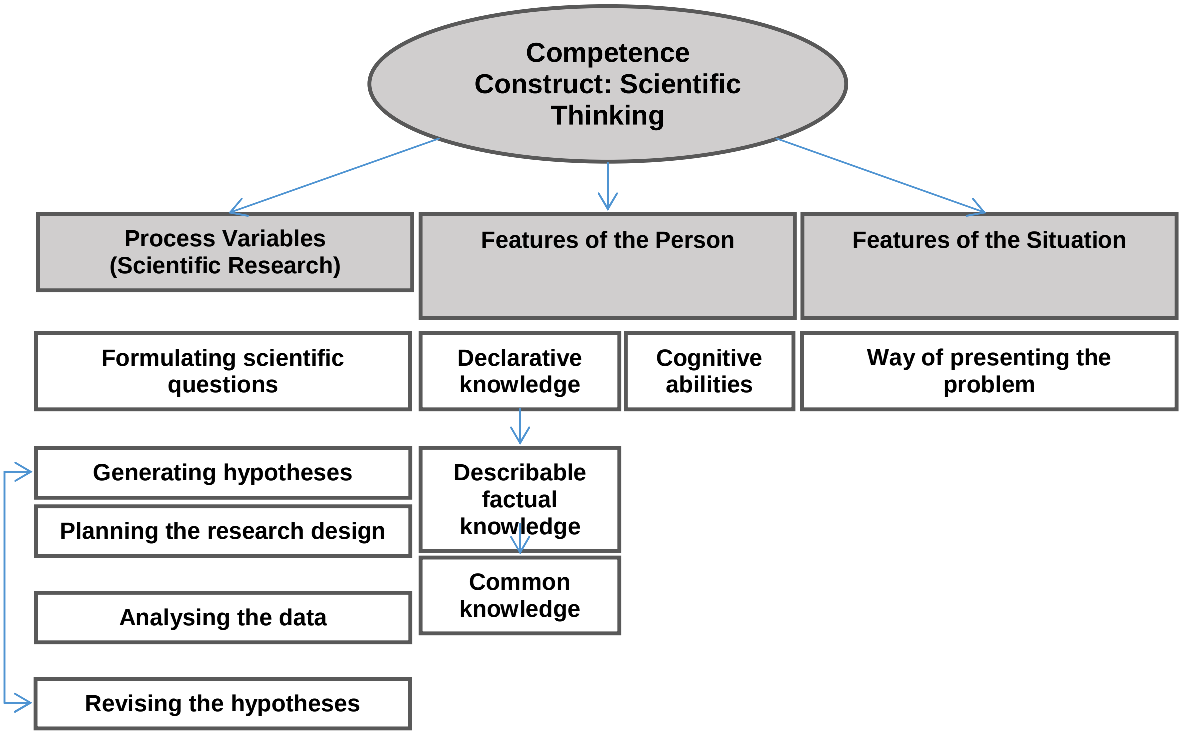


Figure 9. Model based on the competence construct *Scientific Thinking* (author’s own representation based on Mayer 2007). The three decisive aspects (process variables, features of the person and features of the situation), which influence the superordinate competence construct “Scientific Thinking“ are depicted in grey and described by the elements listed below.

Scientific thinking (see figure 9) and the quality of problem-solving depends on the quality of the procedures, the person variables and the situation variables (Mayer, 2007, p. 181). According to Koslowski (1996), Klahr (2000), Mayer et al. (2003), Hammann (2004) and Grube et al. (2007), the formulation of questions, the generation of hypotheses and the planning of an experiment as well as analysis of the data are *the* central constructs (see also figure 9) which can also be found in the national curricula for Biology (Sommer, 2008, p. 19f.). As stipulated in the curriculum, pupils (1) have to notice and develop questions which can be answered with the help of natural scientific knowledge and investigations, and (2) formulate hypotheses, plan suitable experiments for verification, conduct them with respect to safety and environmental aspects and analyse the findings with reference to the hypotheses (Sommer, 2008, p. 19).

Apart from relating the process of problem-solving to the initially formulated hypotheses, the person variables also play an important role. Ziemek et al. (2005) could show that problem-solvers simplify in the area of factual knowledge in case of a cognitive overload in experimental situations, meaning that pupils do not formulate their observations and explanations on a scientific basis but rather with the help of common knowledge (see figure 9).

Scientific thinking in general and the formulation of scientific questions and hypotheses in particular should, however, originate in observing, investigating, describing, comparing and experimenting instead of being an expression of the learner’s autonomous construction. Finally, the quality of problem-solving is also closely related to the relevant situation variables such as how the problem is presented (multiple-choice or practical task). If the problem situation is described poorly because of a short and unclear introduction or a purpose being too vague, pupils only show a very limited systematic and problem-oriented approach. It is not only the processes within the group but also the requirements of practical work and the systematic knowledge-based procedures that have to be managed in collaborative testing situations which cause problems for pupils. They seldom lead to experimental questions and test designs right after the first observations and assumptions. Pupils rather act by the principle of trial and error (Mayer, 2007, p. 182).

This suggests that the process of problem-solving in science classes is substantially influenced by the situation given. It is important to allow the pupils to work freely without leaving them alone; also, there has to be a proper balance between granting autonomy and giving concrete task instructions (Stübig, 2004, p. 13).

In the project “Kolumbus-Kids”, teaching concepts are developed and evaluated, specially adapted to the pupils’ educational needs, integrating the most recent research in psychology and neuroscience. Great emphasis is put on problem- and action-orientation. Scientific-propaedeutical working is promoted when teaching content is discussed with the pupils regarding differences to common knowledge (mostly subjective, not generalizable, and deduced unsystematically) (Dorlöchter, 2004, p. 1). For experimental situations this implies addressing the individual steps during the problem-solving process so that the guidance towards the particular result becomes obvious. The pupils therefore have to understand *why* something is happening (transparency), *how* it is happening (classification) and that it will run similarly or even identically if the same conditions apply (generalization) (see example 3).

Example 3: With all influencing factors (e.g. light) in mind, an experiment about the germination rate of seeds might reveal that the seedlings always germinate in greater number under constant conditions and room temperature compared to growing them at cold temperatures. Regardless of how often the experiment is conducted, the result will always be the same if the experimental requirements and conditions as well as the execution remain unchanged.

This is why knowledge being acquired on the basis of problem-solving processes differs greatly from subjective, unsystematically acquired common knowledge. The engagement with common beliefs and their critical evaluation and classification allows for the promotion of processes of reflected perceptions plus their systematisation and modelling, by that initiating scientific-propaedeutical working (see figure 9 and part 6.1) (Dorlöchter, 2004, p. 1).

The pupils’ own experiences, their common knowledge and curiosity are a good basis for effective questions and finding answers (starting point of exploratory learning) that also require purposeful information research and the engagement with theories and models (Dorlöchter, 2004, p. 1). Apart from combining scientific-propaedeutical working and subject-specific content it is also important to get to know and apply strategies almost independent from the subject. The ability to study successfully will be increased tremendously by possessing methods for literature research and suitable structuring and processing possibilities. Teachers have to know how to integrate meaningful experiments, and thus how to hold scientific-propaedeutical classes, which is why the following recommendations for action are given.

Tips for teachers:

- Do not introduce the problem too openly.
- Provide clear instructions that allow the pupils to work independently, but do not leave them completely alone.
- Coach the pupils in using different methods for literature research and suitable possibilities of structuring and processing their work.
- Discuss the process of scientific working with your pupils and emphasise the differences from common knowledge.
- Use meaningful experiments in everyday teaching.

- Keep safety and environmental aspects in mind when conducting experiments with your pupils.

Conclusion

With regard to future jobs, specific knowledge itself often does not help since certain work areas have not been touched with the content taught in school. Therefore, acquiring competences in science education is considerably more useful, as problem-solving skills, scientific thinking and different learning strategies are imparted. A pupil who is equipped with these abilities can be considered an independent and mature person once he leaves school. Thus, teaching basic concepts in schools is a worthwhile undertaking as they comprise a general understanding of science processes and offer the possibility of linking different topics in terms of superordinate principles such as *energy*, *system*, or *structure and function*. If the sciences are taught according to the basic concepts, students' Scientific Literacy will surely increase.

References

Baumert, J., Klieme, E., Neubrand, M., Prenzel, M., Schiefele, U., Schneider, W., Stanat, P., Tillmann, K. J. & Weiß, M. (Eds.). (2001). *PISA 2000: Basiskompetenzen von Schülerinnen und Schülern im internationalen Vergleich*. Opladen: Leske + Budrich.

Beyer, I. (2008). NATURA. Biologie für Gymnasien. Basiskonzepte. Sekundarstufe I und II. Stuttgart: Klett Verlag.

Carey, S. & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist, 28 (3),* 235-251.

Deutsches PISA-Konsortium (Ed.). (2001). *PISA 2000 - Basiskompetenz von Schülerinnen und Schülern im internationalen Vergleich*. Opladen: Leske + Budrich.

Dorlöchter, H. (2004). Das Weltwissen eines Pädagogikschülers/ einer Pädagogikschülerin und wie / wo man es nutzen kann. In Gutheil, G. & Opora, P. (Eds.), *Perspektiven des Pädagogikunterrichts* (pp. 84-94). Hohengehren: Schneider Verlag.

Dörner, D. (1979). *Problemlösen als Informationsverarbeitung*. Stuttgart: Kohlhammer Verlag.

Engeln, K. & Rost, J. (2006). Increasing students´ interest: Informal learning in authentic science labs. In Xingfeng, L. & Boone, W. (Eds.), *Applications of Rasch Measurement in Science Education*. Maple Grove: Jam Press.

Falkenhausen, E. v. & Vollmer, G. (1985). *Wissenschaftspropädeutik im Biologieunterricht der gymnasialen Oberstufe*. Köln: Aulis Verlag Deubner.

Friedrich, H. & Mandl, H.F. (Eds.). (2006). *Handbuch Lernstrategien*. Göttingen: Hogrefe.

Funke, J. (2003). *Problemlösendes Denken*. Stuttgart: Kohlhammer Verlag.

Funke, J. (2006). *Denken und Problemlösen. Enzyklopädie der Psychologie*. Göttingen: Hogrefe.

Grube, C., Möller, A. & Mayer, J. (2007). *Wissenschaftsmethodische Kompetenzen im Biologieunterricht. In Ausbildung und Professionalisierung von Lehrkräften*. Dusiburg: Internationale Tagung der Sektion Biologiedidaktik.

Gräber, W. (2002). *Scientific literacy: der Beitrag der Naturwissenschaften zur allgemeinen Bildung*. Opladen: Leske + Budrich.

Hammann, M. (2004). Kompetenzentwicklungsmodelle. Merkmale und ihre Bedeutung - dargestellt anhand von Kompetenzen beim Experimentieren. *Der mathematische und naturwissenschaftliche Unterricht, 57(4),* 196-203.

Hofer, B. K. & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67(1),* 88-140.

Klahr, D. (2000). *Exploring Science. The Cognition and Development of Discovery Processes*. Cambridge: MIT.

Klieme, E., Leutner, D. & Wirth, J. (2005). *Problemlösekompetenz von Schülerinnen und Schülern. Diagnostische Ansätze, theoretische Grundlagen und empirische Befunde der deutschen PISA-2000-Studie*. Wiesbaden: VS Verlag.

Koslowski, B. (1996). *Theory and Evidence. The development of scientific reasoning*. Massachusetts: MIT.

Kuhn, D., Amsel, E. & O’Loughlin, M. (1988). *The Development of Scientific Thinking Skills*. San Diego: Academic Press.

Kunter, M., Stanat, P. & Klieme, E. (2003). Kooperatives Problemlösen bei Schülerinnen und Schülern: Die Rolle von individuellen Eingangsvoraussetzungen und Gruppenmerkmalen bei einer kooperativen Problemlöseaufgabe. In Brunner, E., Noack, P., Scholz, G. & Scholl, I. (Eds.), *Diagnose und Intervention in schulischen Handlungsfeldern* (pp. 89-110). Münster: Waxmann Verlag.

Ledermann, N. G., Abd-El-Kahlick, F., Bell, R. L. & Schwartz, R. S. (2002). Views of nature of Science Questionnaire: Toward valid and meaningful assessment of learners´ conceptions of nature of science. *Journal of Research in Science Teaching, 39,* 497-521.

Lichtner, H.-D. (2007). *Zum Umgang mit Basiskonzepten im Unterricht (Schwerpunkt Sek I).* Retrieved from http://www.biologieunterricht.homepage.t-online.de/Biodateien/ Umgang%20Basiskonzepte.pdf.

Lichtner, H.-D. (2007). *Strukturierendes Lernen in der Biologie mit Basiskonzepten*. Retrieved from http://www.biologieunterricht.org/Basiskonzepte.pdf.

Martin, M. O., Mullis, I. V. S., Gonzales, E. J. & Chrostowski, S.J. (Eds.). (2004). *TIMSS 2003 International Science Report*. Boston: TIMSS & PIRLS International Study Center, Lynch School of Education.

Mayer, J., Keiner, K., & Ziemek, H. (2003). Naturwissenschaftliche Problemlösekompetenz im Biologieunterricht. In Bauer, A. et al. (Eds.), *Entwicklung von Wissen und Kompetenzen im Biologieunterricht* (pp. 21-24). Berlin: IPN.

Mayer, J. (2007). Erkenntnisgewinnung als wissenschaftliches Problemlösen. In D. Krüger & H. Vogt (Eds.), *Handbuch der Theorien in der biologiedidaktischen Forschung: Ein Handbuch für Lehramtsstudenten und Doktoranden* (pp. 177-186). Berlin: Springer Verlag.

Mullis, I. V. S., Martin, M. O., Ruddock, G. J., O´Sullivan, C. Y., Arora, A., & Erberber, E. (Eds.). (2005). *TIMSS 2007 Assessment Frameworks*. Boston: TIMSS & PIRLS International Study Center, Lynch School Education.

OECD (1999): *Measuring student knowledge and skills: A new framework for assessment*. Paris: OECD Publishing.

Okada, T. & Simon, H. A. (1995). Collaborative discovery in a scientific domain. In J. D. Moore & J. F. Lehmann (Eds.), *Cognitive Science Society Proceedings of the Seventeenth Annual Conference of the Cognitive Science Society* (pp. 340-345). Pennsylvania: University of Pittsburgh.

Prenzel, M., Baumert, J., Blum, W., Lehmann, R., Leutner, D., Neubrand, M., Pekrun, R., Rolff, H.-G., Rost, J. & Schiefele, U. (Eds.). (2004). *PISA 2003. Der Bildungsstand der deutschen Jugendlichen in Deutschland - Ergebnisse des zweiten internationalen Vergleichs*. Waxmann Verlag. Münster.

Prenzel, M., Artelt, C., Baumert, J., Blum, W., Hammann, M., Klieme, E., & Pekrun, R. (Eds.). (2007). *PISA ´06 - Die Ergebnisse der dritten internationalen Vergleichsstudie*. Münster: Waxmann Verlag.

Sommer, Barbara (2008). Kernlehrplan für das Fach Biologie für die Jahrgangsstufen 5 – 9 in Gymnasien des Landes Nordrhein-Westfalen. Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen. [Core Curriculum for Biology North Rhine-Westphalia] Retrieved from www.standardsicherung.schulministerium.nrw.de/lehrplaene/upload/ lehrplaene_download/gymnasium_g8/gym8_biologie.pdf

Stübig, F. (2004). *Lernen an Stationen. Ein Beitrag zum selbständigen Lernen*. Kassel: University Press.

Wamek, S. (1985). *Wissenschaft im Unterricht - Keine ewigen Gesetze*. DIE ZEIT, 51.

Wegner, C., & Minnaert, L. (2012). Promoting future scientists: the project Kolumbus-Kids. *Education in Science*, *249*, 20–21.

Wegner, C., Minnaert, L., & Strehlke, F. (2013). The Kolumbus-Kids project in Germany for gifted children. *Primary Science, 130*, 16–20.

Ziemek, H., Keiner, K., & Mayer, J. (2005). Problemlöseprozesse von Schülern der Biologie im naturwissenschaftlichen Unterricht - Ergebnisse quantitativer und qualitativer Studien. In R. Klee, A. Sandmann & H. Vogt (Eds.), *Lehr- und Lernforschung in der Biologiedidaktik, Volume 2* (pp. 29-40). Innsbruck: Studienverlag.