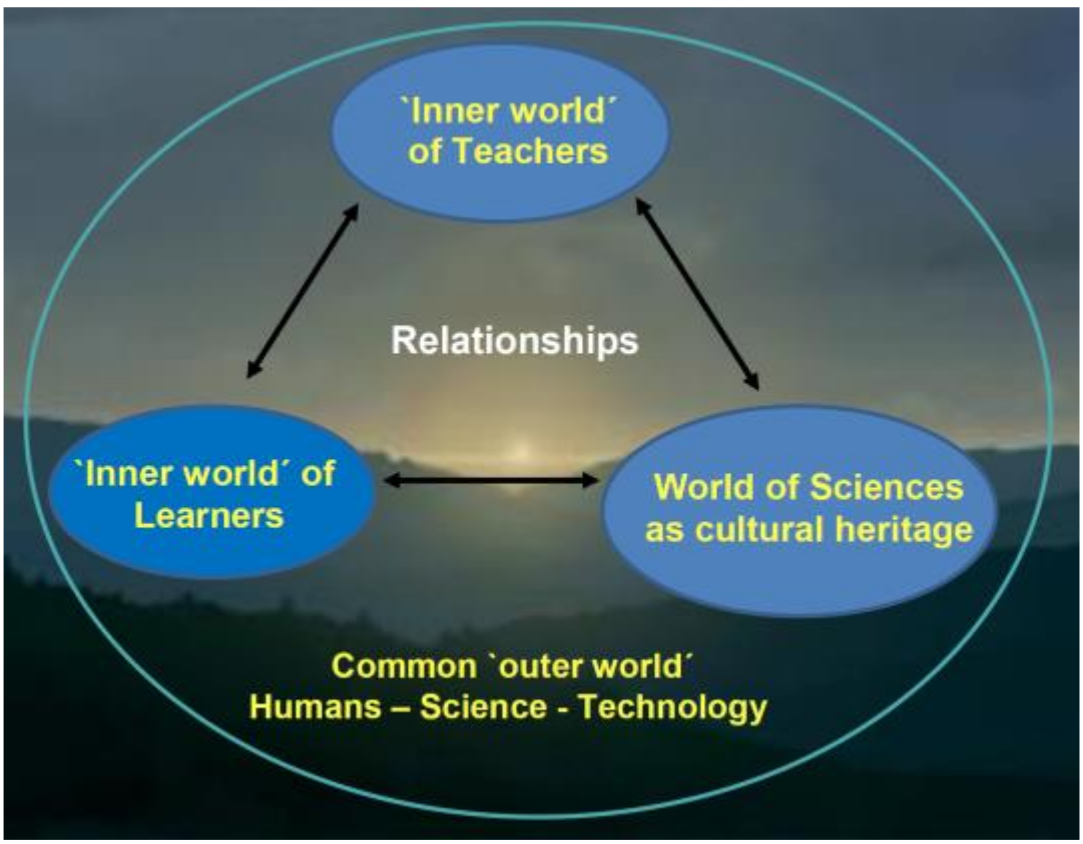
# Gemeinsamer Referenzrahmen für Naturwissenschaften (GeRRN)

# Common Framework of Reference for the Natural Sciences (CoFReNS)

A suggestion as to what scientific education should be like today

*2nd Revised Edition 2017*

BIRGIT EISNER, ULRICH KATTMANN, MATTHIAS KREMER, JÜRGEN LANGLET, DIETER PLAPPERT, BERND RALLE




VERBAND ZUR FÖRDERUNG
DES MINT-UNTERRICHTS
BUNDESVERBAND

**Contents**

**Introduction**

**01 Objectives and reference levels**

**02 Reference levels for process-related scientific skills**

**03 Reference levels for content-related scientific skills**

**04 Content-related scientific skills**

*04.1 Interdisciplinary*
- NOS: the cultural significance of science
- Humankind, nature, technology: climate change

*04.2 Biology*
- Evolution: explaining natural history scientifically
- The organism: the importance of health and illness
- Relationships between Humans and Nature: creating and preserving our environment

*04.3 Chemistry*
- Matter: how properties, structure and use of substances are related
- Chemical reactions: what do we mean by “A new substance is formed”?

*04.4 Physics*
- Matter: from the very large to the very small
- Theory: making nature calculable
- Energy: the supply of electrical energy in everyday life

**05 Promoting Education: changing learning and teaching in the natural sciences**

*05.1 The current situation and previous attempts to change it*

*05.2 Consequences*

*05.3 Discussion of educational content on the basis of the Common Framework*

*05.4 Looking ahead: conclusions for learning and teaching natural sciences*

**Literature**

## Introduction

This revised edition of the Common Framework of Reference for the Natural Sciences (CoFReNS, Gemeinsamer Referenzrahmen für Naturwissenschaften, GeRRN) is the result of the public presentation and discussion of the first edition of the framework during the MNU Federal Congress 2017 in Aachen. Since 2014 the process of developing a framework for education in the natural sciences has been promoted actively by the MNU (German Association for the Promotion of Mathematical and Scientific Teaching) in order to support teaching in the MINT subjects. We are greatly indebted to all participating MNU members and representatives of national and international associations who provided input for the creation of this framework. In particular we want to say thank you to the numerous associations and colleagues who responded to our request for feedback on the first edition of the framework; their comments and suggestions have been taken into account in this revised edition.

The Executive Committee of the MNU acknowledges with gratitude the contributions made especially by the following:

- the former federal chairman, JÜRGEN LANGLET, who had developed and promoted the idea of a GeRRN/CoFReNS, as well as the MNU consultant for the subjects, MATTHIAS KREMER, whose unremitting efforts have helped to reach the goal in the shape of the GeRRN/CoFReNS so quickly.
- the authoring group consisting of BIRGIT EISNER, ULRICH KATTMANN, MATTHIAS KREMER, JÜRGEN LANGLET, DIETER PLAPPERT, BERND RALLE, who wrote and revised the first edition and who linked it with the invitation to „Promoting Education: Changing the teaching and learning in the natural sciences“ (EISNER et al., MNU 3/2017)
- the members of the expert groups who did the hard preparatory work of choosing the subject-specific competences that are important for the GeRRN/CoFReNS and assigning them to different levels.
  Biology: JÜRGEN LANGLET, JOACHIM BECKER, MATHIAS EBEL, SVEN OSTERHAGE, JULIA SCHWANEWEDEL, WALTRAUD SUWELACK, HEIKE WEILE, JÖRG ZABEL
  Chemistry: MATTHIAS KREMER, ULRICH BEE, ANKE DOMROSE, BERND RALLE, ROBERT STEPHANI, JUDITH WAMBACH-LAICHER
  Physics: BIRGIT EISNER, GERWALD HECKMANN, PETER HEERING, LUTZ KASPER, RAINER KUNZE, ELKE RIEDL, UTE SCHLOBINSKI-VOIGT

We hope that the present proposal of a framework of reference may have an effect in two ways. Firstly that these ideas will be discussed all over Europe, modified, adjusted and revised in such a way that scientific education will play a more important role in Europe, from which we can all benefit. And secondly, it seems to be equally useful or even necessary to create a framework of reference for the subjects of mathematics, technology education and computer science, all of which are part of the MNU.

We are pleased to recognize that the other MINT subjects are making initial attempts to adopt the ideas presented by the MNU, and we are looking forward to working closely together with other associations to create a common and indeed a European Framework of Reference for all MINT subjects.

Düsseldorf, 15. October 2017

On behalf of the Executive Committee of the MNU
GERWALD HECKMANN, Chairman

## 01
## Objectives and reference levels

The statement that a person's education must also include knowledge, skills and relationships to nature and natural sciences is today agreed. Not only because the natural sciences constitute a part of our cultural heritage, as do music, literature or philosophy, but also because they form part of general education and thus of a meaningful everyday way of life. In addition, in the future we will need to solve many important problems which will require a sufficient number of qualified scientists. Another important factor is that political decisions on technical questions will need to be taken: in democratic countries such questions must be shared and understood by as many citizens as possible, so that they are able to support such decisions on the basis of their own scientific knowledge.

The European Commission has therefore published a European Qualification Framework (EUROPEAN COMMISSION, 2007), which describes "basic scientific and technical competence" as one of eight key competences. According to this, natural science competence is "the ability and willingness to explain the natural world on the basis of existent knowledge and certain methods in order to ask questions and to draw conclusions based on evidence." It is also connected with the understanding of changes caused by human activities and with a sense of responsibility as a citizen. Knowledge means knowing the basic principles of the natural world, basic scientific concepts, principles and methods, technology, technical products and procedures. The abilities and attitudes of natural sciences are described in a similarly general form. However, we need to ask what are the basic principles, the scientific concepts, the principles and methods that are part of this ability to explain the world? The question then arises as to how teaching in the field of natural sciences can promote the inner motivation of lifelong learning. If we try to reach a consensus, it quickly becomes clear that opinions diverge and that only a social negotiation process can lead to a desirable outcome. The present document has the goal of making this possible across Europe.

The European Commission's framework of reference also raises another question: each individual has his or her own depth of penetration into the understanding of natural science. In order to be able to make a statement as to how education related to natural sciences should look, it must be possible to specify an educational aspect at different levels. At this point, the tried and tested "Common European Framework of Reference for Languages" (GOETHE-INSTITUT 2002) is very useful. It describes level steps, which the GeRRN/CoFReNS follows, so as to be able to serve as a basis for determining educational standards. To create a complete canon of all scientific contents would however be presumptuous and ineffective. This proposal, selecting as it does examples from academic and multidisciplinary topics and presenting process-related competences, instead describes instead content at the various different levels.

At first sight, the GeRRN/CoFReNS could be seen as an educational plan for different types of school. However, that is not its aim. The GeRRN/CoFReNS chooses a new approach: it does not specify which lessons and topics should be taught in the classroom and which competences should be acquired, as in a curriculum, but rather defines which natural science competences need to be found in our society, according to our agreement of natural sciences (to be discussed below), graded according to five different levels.

It is obvious that this forms a goal for schools and other educational institutions: how can we achieve this level of education? Here too, the procedure is the same as for the reference framework for languages, which has the subtitle "Learning, teaching, judging" (GOETHE-INSTITUT 2002). In chapter 05 "Promoting Education: changing learning and teaching in the Natural Sciences", fundamental statements about the acquisition of scientific competences[1] will be made.

The GeRRN/CoFReNS framework explains the contents and competences of a few selected central scientific concepts by means of examples. Relevant everyday concepts examine whether it is necessary to revise these ideas at certain levels in order to obtain more sustainable concepts.

Thus GeRRN/CoFReNS has a dual role: it is both a means of describing and determining the levels of the natural science education of an individual and also provides input to educational institutions for the formulation of educational standards and curricula as well as perspectives for learning and teaching in the natural sciences.

The objectives of the GeRRN/CoFReNS are:

- Strengthening natural sciences as part of the cultural heritage of humankind in both school and society;
- A coherent, age-appropriate development of natural science study for each individual from the beginning to the end of their formal education, providing the ability for a lifelong extension of their own competences;
- Increased acceptance by students and sustainability of learning in natural sciences by means of age-related, non-excessive requirements;
- The decisive criterion in the selection of items to be learned should not be their role in the *current* school syllabus, but rather the question as to whether and why the things to be taught actually add value to an individual at a certain particular educational and cultural level, both now and in his future (school and post-school) life.
- Strengthening of development of a sustainable meaning of science education by securing and deepening (by means of spiral curricula) of the particular level achieved.

[1] The term "competences" is used to describe skills with cognitive, emotional and behavioral aspects.

## Common reference levels

The reference levels follow those defined for the reference framework for languages and are set out in detail in Table 1. There are two main differences to the situation in the languages:

The reference levels of the C level correspond to the natural science education of an expert, i.e. they are to be assigned to the Bachelor's degree (C1) or Master (C2) in a science subject. The content description of these levels is certainly a very meaningful task, but falls within the competence of university representatives and will not be pursued within this framework.

An additional level B1 + has been added to the reference frame for languages. It has been found that many more abstract aspects are applied in the natural sciences which go beyond level B1. B1 + therefore describes competences which are required to once achieve the reference level B2 of a well-educated non-scientist, without already achieving its depth. One example is knowledge about atoms and molecules (see 04.2 Chemistry. Matter: how properties, structure and use of substances are related).

| **Elementary Education in natural sciences** | | **General Education in natural sciences** | | |
|---|---|---|---|---|
| | | | | |
| **A1** | **A2** | **B1** | **B1+** | **B2** |
| **Experience of and dealing with phenomena in nature and technology** | **Proper perception and personal interpretation when dealing with phenomena in nature and technology** | **Knowledge and application of basic scientific concepts** | **Being familiar with the central concepts and ideas of natural sciences as well as applying them independently and reflecting on them** | **Being familiar with central concepts and theories of natural sciences, reflecting on and evaluating them independently** |

Tab. 1. Reference levels of science-related education

The bottom line of Table 1 contains statements about the expected levels of activity, abilities, or the depth of penetration of a particular person at this educational level.

A person's education often develops independently of his school leaving qualification. Nevertheless, a loose link between school levels and reference levels can be established. For example, teaching in a natural science subject to a university entrance level should be designed in such a way that, even years later, the competences of the level B2 of the GeRRN/CoFReNS are still present. Since it is natural that technical terms and names will be forgotten in the course of time, competences can only be formulated in general terms and refer to concepts rather than to details.

In the same way as between university entrance level and B2, the relationship between A1 and education in the parental home and kindergarten (i.e. before starting school) can be established between A2 and B1 as well as B1 and the middle school leaving qualification. If a student acquires the right to attend a course leading to a university entrance level, he or she should have demonstrably acquired the level B1+ competences.

## 02

## Reference levels for process-related scientific skills

Reference levels (levels) should describe an expected final state. Thus, no statement is made about the processes of teaching or non-formal education (education outside school). Nevertheless, the levels of process-related competences summarized in Table 2 can provide important impulses for the teaching process itself. In order to be able to use meaningful conceptions instead of empty phrases, it is useful in the learning process to connect to all the previous levels. If a certain level has not been reached, we need to go through it for the first time, i.e. to build on the diagnosed initial state, regardless of age but depending on previous development. In this way, the prerequisites are created for progressing from a simple to a more profound structure of the knowledge to be learned, and to a genuine understanding of the scientific context according to Piaget´s reference levels of cognitive development.[2] Those ideas, which are based on the work of PLAPPERT (2011), are presented in more detail in chapter 05. Table 2 lists the corresponding competences for the five levels (see Table 1).

[2] These terms are due to PIAGET but can still be used independently of his theory (cf HATTIE 2014) to describe the phenomena to be observed in learners.

| | |
|---|---|
| **A1** | **Experience of and dealing with phenomena in nature and technology**<br>Establishing a personal relationship through experiences with phenomena:<br>*One can*<br>– *“research playfully“at leisure,*<br>– *express oneself in an elementary, personal everyday language, in a disordered manner, childlike, without using technical terms,*<br>– *ask questions about phenomena in nature and technology, as well as find one’s own explanations.*<br>Corresponds more or less to the state before entering school. |
| **A2** | **Proper perception and interpretation when dealing with phenomena in nature and technology.**<br>Establishing a personal relationship to phenomena and describing them properly:<br>*One can*<br>– *qualitatively investigate simple phenomena and contexts,*<br>– *describe them objectively in everyday language,*<br>– *use initial technical terms appropriately.*<br>Corresponds to the state at the end of primary school. |
| **B1** | **Knowledge and application of basic scientific concepts**<br>Establishing a personal relationship to phenomena and describing them properly within their contexts as the basis of natural sciences:<br>*One can*<br>– *investigate phenomena and simple relationships,*<br>– *make increasing use of qualitative terms and elementary viable models,*<br>*give elementary personal reviews of scientific facts.*<br>Corresponds to the state at the end of lower secondary school level |
| **B1+** | **Know central concepts and ideas of the natural sciences and apply them independently and reflect on them.**<br>Establishing a personal relationship, factual and scientific description and justification of phenomena and relationships:<br>*One can*<br>– *investigate relationships independently, both qualitatively and quantitatively,*<br>– *deal appropriately with central technical terms and concepts, also using appropriate models, while critically reflecting on the limits of model formation and establishing personal evaluations of simple relationships.*<br>Corresponds to the state at the end of lower secondary school level, but with the right to access to natural science courses of the “gymnasiale Oberstufe” (upper secondary school, B2). |

| | |
|---|---|
| **B2** | **Know central concepts and theories of natural sciences, independently reflect on and evaluate them.**<br>Establishing a personal relationship, appropriate and deepened scientific description and explanation:<br>*One can*<br>– *examine and investigate relationships with increasing complexity and autonomy,*<br>– *dealing with technical terms and concepts qualitatively and quantitatively with increasing sharpness and complexity,*<br>– *deal critically with statements on natural science issues and understand epistemological considerations,*<br>– *carry out a personal assessment of interrelationships with increasing complexity and formulate appropriately to the ability of the addressee.*<br><br>Corresponds to the level of access to higher education at university level in a science subject) |

Tab. 2. Common reference levels for process-related scientific skills. [3]

[3] For a more detailed overview of the German Education System see http://uis.unesco.org/en/isced-mappings and choose `Germany´.

# 03
# Reference levels for content-related scientific skills

An attempt to create a canon of all scientific skills and knowledge would be neither reasonable nor possible. Therefore, GeRRN/CoFReNS provides a clear presentation on the basis of only a few central theories or concepts of a subject. The competences mentioned therein are illustrated by examples which provide the underlying factual knowledge as well as its connection to the world around us, thus bringing important contexts into play. In this way, the "three-pillar model of basic scientific education" is taken up in the following tables, as shown in Figure 1.

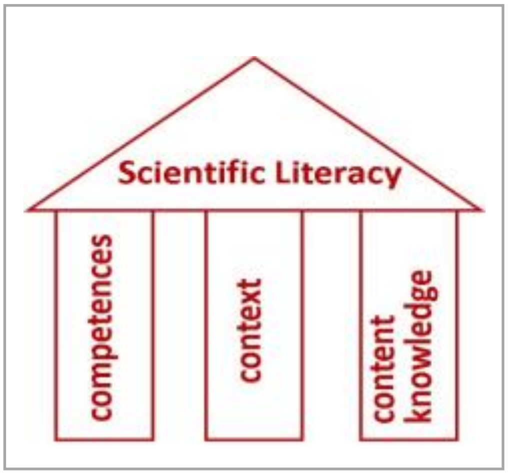



Fig.1 Three-pillar model of basic scientific education (according to RHEINLAND-PFALZ 2014)

The following GeRRN/CoFReNS tables include an additional column, separated from the above three, which contains examples of students' everyday conceptions. These are largely independent of levels, as they remain available across the stages, but they illustrate the importance of the competences formulated. They specify the ideas and thinking habits that must be expected in the given teaching context in order to be able to build on them in class. These conceptions are only revised when the relevant level is reached (BARKE, 2006, DUIT, 2009, HAMMANN & ASSHOFF, 2014, KATTMANN, 2015). “Revise" means that the facts are looked at afresh, so that a new perspective is achieved.

Although the natural sciences are always mentioned together, each subject has its own "spectacles" through which the world and its processes are viewed (MNU, 2004). For this reason, the following tables list the different subjects separately. However, as important interdisciplinary contexts, two topics were added at the beginning of the subject-specific tables in Chapter 04.1: Knowledge of the Nature of Science, NOS: the cultural significance of science. This is just as much a part of general education as the second interdisciplinary area, which is of highly significant importance for the future for humankind, nature and technology: climate change.

The subject-related competences are divided as follows:
04.2 Biology
    Evolution: explaining natural history scientifically

The organism: the importance of health and illness

Relationships between Humans and Nature: creating and preserving our environment

04.3 Chemistry

Matter: how properties, structure and the use of substances are related

Chemical Reactions: what do we mean by "A new substance is formed"?

04.4 Physics

Matter: From the very large and the very small

Theory: Making nature calculable

Energy: The supply of electrical energy in everyday life

As can be seen from this overview, the following tables give an example of how sustainable competences relating to natural sciences should look at different levels. The competences in the field of knowledge generation, and in particular the experimental competences, which are important for teaching, cannot of course be included using this approach, since adults normally have little opportunity to carry out experiments. However, knowledge about experimentation as well as small experiments which are possible in everyday life are listed below.

# 04 Content-related scientific skills

## 04.1 Interdisciplinary. NOS: the cultural significance of science

A look at human history reveals that the development of societies is closely intertwined with the development of science and technology. The knowledge that the further development of our high-tech world (with all its opportunities and risks) will inevitably lead to a change in the social environment, makes it possible for young people to act in a responsible and forward-looking manner.

| GeRRN/CoFReNS- Skills<br><br>A person at this level of scientific education …. | | Examples / Explanations | Everyday ideas<br><br>which are revised when the relevant competence is reached |
|---|---|---|---|
| A1 | can give examples from the world around him/her of changes from the past to today, which are due to natural science and technology. | at this stage, everyday experience prevails, the natural sciences are behind it:<br><br>motion with horse-drawn carriages compared with by car<br><br>cooking on a fire or an electric stove<br><br>in earlier times, other kinds of food were produced and eaten<br><br>in the past there was no plastic, while even earlier knives were made of stone and not of metal | |
| | can imaginatively outline possible changes in the future. | | Technical progress is always good.<br><br>Technical progress destroys the environment. |

| | | | |
|---|---|---|---|
| A2 | can illustrate examples of technical developments in a proper, age-appropriate everyday language. | nutrition, mobility, electrical energy, heating, other consumables<br><br>plant and animal breeding<br><br>medical equipment<br><br>clothes, fertilisers, medicaments | Technical advances are purely random discoveries. |
| B1 | can show simple examples of how scientific knowledge has been historically developed. | transition from a geo- to a heliocentric world view<br><br>from the origin of life to the reproduction of organisms<br><br>concepts of the structure of atoms<br><br>ideas as to how combustion occurs | Scientific statements are always true. |
| | can describe examples of technical applications which are based on scientific findings. | the industrial revolution - development of the steam engine, development of transport systems, use of electrical energy (lighting, drive systems)<br><br>vaccination<br><br>simple examples of genetic engineering<br><br>metal production from ores<br><br>oil distillation for fuels | Natural science and technology are the same. |

| | | | |
|---|---|---|---|
| | can outline the lives of selected researchers in a historical context. | personalities who have described and explained important scientific phenomena in an understandable manner, e.g. Isaac Newton, Charles Darwin, Antoine Lavoisier, Albert Einstein, Alfred Wegener | |
| | can present an example showing that scientific descriptions often oversimplify. | planetary motion in the solar system<br><br>combustions in air, neglecting by-products such as nitrogen oxides | Natural science describes reality as it is. |
| B1+ | can describe examples of technical applications which are based on technological use of scientific findings | electromagnetic induction for providing electrical energy<br><br>duplication of DNA by PCR<br><br>catalysts in vehicles, dosage of the air supply<br><br>MRT | |

| | | | |
|---|---|---|---|
| | can put the lives and achievements of selected researchers into a historical context. | RÖNTGEN's discovery in the context of the technical progress of the nineteenth century<br><br>the achievements of the teacher OHM for the further development of the theory of electricity<br><br>DARWIN'S theory of evolution in the context of ideas of the constancy of species and speculative concepts of evolution<br><br>discovery of nuclear fission by OTTO HAHN and LISE MEITNER and the development of the atomic bomb in the Second World War<br><br>discovery of penicillin (ALEXANDER FLEMING) | Natural science is independent of historical and social conditions. |
| | can explain how scientific descriptions, models and laws have been changed. | changes in the image of the world due to ARISTOTELES, PTOLEMY, KOPERNICUS and KEPLER, including modern cosmology<br><br>atomic models<br><br>the theory of catalysis;<br><br>concepts of the gene<br><br>plate tectonics | Natural science statements are timeless. |

| | | | |
|---|---|---|---|
| B2 | can present selected examples of how scientific theories were historically developed. | Historical development of ancient light concepts, about particle model (NEWTON) and the beam model of light, from the wave nature to the quantum-physical photon idea<br><br>identification of genetic material, from proteins to DNA and epigenetic influences<br><br>development of the theory of oxidation by LAVOISIER<br><br>the term "acid": from acidic solutions via certain substances to the term proton donor | |
| | can describe examples of how scientific and technical knowledge influence each other. | advancing the manual and technical development of vacuum pumps through research carried out in the 17th century and its influence on the formulation of the gas laws<br><br>findings of cytology and microbiology due to the development of light and electron microscopes<br><br>oxidation and reduction in metal production | Scientific findings affect technical progress, but not vice versa. |

| | | | |
|---|---|---|---|
| | can describe ways of gaining knowledge in the natural sciences, their hypothetical character and their limits. | critical-rational limitation of natural science to hypotheses that can be verified by observation and experiment<br><br>natural science is to be understood as a specific approach to a world understanding. Exact statements apply only under certain conditions (if-then statements) | Scientific theories represent secured knowledge.<br><br>The natural sciences provide the only source of knowledge. |
| | can outline social structures that exist within historical and current scientific research. | any successful researcher is part of a large team containing project leaders, assistants and many other persons<br><br>cooperation of persons from different disciplines. | Researchers work like hermits. |
| | can explain that scientific knowledge is provisional. | the temporary nature of the modern description of the world;<br><br>examples: development of theories on the nature of light, theories on heredity, phlogiston vs oxidation theory, discovery of the nanoscale as a further dimension between substance and particle level | Today's ideas about the natural sciences will not need to be revised in the future. |
| | can classify and evaluate science as a cross-cultural achievement. | the natural sciences have developed over thousands of years in different cultures | Natural sciences are an achievement of the Western world. |

## 04.1 Interdisciplinary. Humankind, nature, technology: climate change

The human influence on the development of the Earth's climate is a central issue for the survival of humankind. Today's adolescents will be existentially affected during their lives by whether the objectives defined in the United Nations Framework Convention on Climate Change will be achieved or not. In order to make appropriate personal and social decisions, a profound knowledge of natural sciences and a corresponding ability to act are particularly necessary, in addition to economic and sociological knowledge. Only then can responsible creativity lead to far-sighted intelligent solutions.

| | **GeRRN/CoFReNS - Skills**<br><br>**A person at this level of scientific education ….** | **Examples / Explanations** | **Everyday ideas**<br><br>**which are revised when the relevant competence is reached** |
|---|---|---|---|
| A1 | can experience and communicate the beauty and the seasonal development of nature. | relationship with nature is experienced as worthwhile and is established when playing, walking and hiking in nature, or when planting in a flowerbed | |
| | can explain simple production processes of food in his own words. | bread or cake baking, milling grain, making jam | Food is always available. |
| | can behave in such a way that he or she is careful with natural and human-made resources and energy. | lighting, heating and ventilation<br><br>sensibly used food, careful handling of food | Our own behaviour and global developments are not interrelated. |
| A2 | can describe the basic relationships of food production, mobility, heating of houses, the use of electrical energy and other consumption in a factually correct everyday language. | energy use in manufacturing processes of consumer products such as: fruit and vegetables, milk, cheese, pasta, sugar, salt, cooking oil production<br><br>different types of heating<br><br>various possibilities of generating electrical energy | |

| | | | |
|---|---|---|---|
| | can exhibit resource-saving behaviour and explain this behaviour in an appropriate everyday language. | sensible handling of food, intelligent heating, economical use of electrical energy, targeted shopping | Fast driving consumes less fuel, as the driving time is shorter. |
| | can produce his own food and other products of daily use using a recipe in a resource-saving manner. | cake, bread, pasta, simple dishes, jam, juice, soap | |
| B1 | can name essential plants and animals which occur in the personal sphere of life. | | |
| | can qualitatively explain the greenhouse effect. | radiation equilibrium sun-earth, different effects of visible light and thermal radiation, main greenhouse gases | Radiation is reflected from the earth and reflected back at the upper boundary or ozone layer.<br><br>Radiation comes in through the ozone hole and no longer finds an exit because it is reflected by the boundary layer.<br><br>The so-called greenhouse effect uses the analogy with a greenhouse, where glass panes prevent heat exchange. |
| | can name the important components of the air and its approximate composition. | nitrogen (about 80%), oxygen (about 20%), carbon dioxide (about 0.04%), water (about 3-4%). Concept of relative humidity | Carbon dioxide or oxygen as dominant components of the air |

| | | | |
|---|---|---|---|
| | can describe the causes and effects of the anthropogenic contribution. | carbon cycle, ratio of the main greenhouse gases, increase in greenhouse gases in the past, central predictions of climate models | "Artificial" carbon dioxide does not enter the circulation, but remains in the atmosphere. |
| | can identify and justify important social and personal measures towards reducing the anthropogenic contribution. | examples of nutrition, mobility, heating, supply of electrical energy, other consumption | |
| | can explain the two-degree target for the increase in global temperature. | reduce emission of carbon dioxide and other climate-changing gases, and remove more carbon dioxide from the atmosphere to reach flow equilibrium | Only reducing carbon dioxide emissions is important.<br>The only greenhouse gas is carbon dioxide. |
| B1+ | can explain the functioning of thermal power plants and their energetic efficiency. | coal, nuclear, solar power plants | |
| | can plan, implement and evaluate his own energy-turning projects. | | |
| | can represent the greenhouse effect in depth with first quantitative considerations. | quantitative estimation of the effects of the most important greenhouse gases, predictions of climate models and the relationship between temperature rise and the impact on life on earth | Confusion and mixing with stratospheric ozone aspects. |
| | can give a quantitative justification of important social and personal measures to reduce the anthropogenic component. | comparison of energy flow diagrams for plant and animal nutrition, quantitative comparison of different measures for the thermal insulation of houses | |

| | | | |
|---|---|---|---|
| B2 | can outline quantitatively the importance of entropy production and energy degradation for the efficient use of energy. | heat pump: heating with minimal entropy generation, electric motors compared to internal combustion engines, minimum entropy generation | |
| | can conceive quantitatively documented measures for the country, the city and for him/herself and evaluate them using ecological, economic and sociological criteria. | ecological footprint | |
| | can elucidate the system concept using the example of the greenhouse effect and its anthropogenic contribution. | examples of systems: electrical circuit and water circuit. Local changes always affect the whole system | |
| | can explain natural climate change and the human influence on it, in a differentiated manner, using central quantitative data and the correct terms. | Report on current scientific state, Intergovernmental Panel on Climate Change (IPCC) | Ideas from "fake news" and alternative explanatory models. |
| | can provide global and personal measures for the reduction of the anthropogenic greenhouse effect using the correct technical terms. | United Nations Framework Convention on Climate Change (UNFCCC), global calculation models | |
| | can choose a suitable example to describe the interaction of the ecological, economic and social impact of a measure and to justify a personal decision. | | |
| | can present proposals on how to increase the acceptance of climate protection measures in politics, in the economy as well as by the general public. | | |

## 0 4.2 Biology. Evolution: explaining natural history scientifically

Adults should see nature in terms of natural history, regard diversity as positive, and be able to substantiate the universal validity of the theory of evolution and natural selection.

Humans – Nature – Relationships: modifying and preserving our environment

| **GeRRN/CoFReNS - Skills**<br><br>**A person at this level of scientific education ….** | | **Examples / explanations** | **Everyday ideas**<br><br>**which are revised when the relevant competence is reached** |
|---|---|---|---|
| A1 | can name creatures from the earth's history | dinosaurs | |
| A2 | can explain the role of the breeder in breeding (artificial selection) and describe the results. | pets, breeds of horses, cows etc | Under- and overestimation of human influence. |
| | can describe the history of and relation between creatures. | vertebrates, moving from water to land | Sudden changes and fragmentary succession, e.g. bacteria-dinosaur-human. |
| | can explain inheritance busing simple examples. | phenomenological occurrence of features | |
| B1 | can describe the history of species in terms of descent from common ancestors. | humans are descended from a former species of apes. | Species living today are ancestors of future more developed species; thus monkeys are the ancestors of humans. |
| | can explain kinship by means of biological ancestry. | | Kinship means similarity. |
| | can explain changes in and adaptation of populations by means of evolutionary factors. | variation and selection<br><br>origin of giraffe and okapi | Living beings adapt to the environment deliberately and purposefully. |

| | | | |
|---|---|---|---|
| | can explain lineages originating from common ancestors as branching, i.e. adaptation to different living conditions. | hominids, vertebrates | Evolution means positive development |
| | can justify that the concept of race in humans is obsolete. | larger differences (diversity) within the groups, gradual transitions features | There are different races of humans, which are different in their nature. |
| | can describe how the earth has been transformed by living creatures in the course of its history. | enrichment of oxygen in the bioplanet earth | Living beings are passively adapted to their environment. |
| B1+ | can name mutations and recombination as causes of variability | | Mutations are always harmful. |
| | can explain adaptation as a result of mutation, recombination and selection. | | Adaptation takes place deliberately and purposefully. |
| | can explain that adaptation is never perfect. | | Living beings are perfectly adapted. |
| | can explain speciation as a result of evolution. | | |
| | can present genetic arguments against racism. | differences between human groups exist only in the frequency of the alleles | |
| B2 | can interpret molecular biological data as evidence for evolution. | | |
| | can weigh up different concepts of species and define species formation by means of genetic isolation of populations. | | Species is a uniform type of living being: all individuals are equal. Species change in the same way as an individual: all members change at the same time and in the same way |

| | | | |
|---|---|---|---|
| | can explain how co-evolution is a source of continual evolution. | | In a constant environment, no evolution takes place. |
| | can apply evolution theory to various areas of biology. | behaviour, immune response, resistances | |
| | can reflect the role of theories in the natural sciences. | | "Theories" are non-binding theoretical concepts |
| | can compare different evolutionary theories and differentiate them from non-scientific concepts. | different ideas of creation, creationism | Evolution is "only" a theory. |

## 04.2 Biology. The organism: the importance of health and illness

An adult should have knowledge (cell biology, physiology, genetics) and attitudes to maintain and promote his health as well as deal with illness and disability.

| **GeRRN/CoFReNS Skills**<br><br>**A person at this level of scientific education ….** | | **Examples / explanations** | **Everyday ideas**<br><br>**which are revised when the relevant competence is reached** |
|---|---|---|---|
| A1 | can move and learn playfully, eat together with others, and playfully experience physical phenomena. | breathing, heartbeat, sensory perceptions | |
| | can talk about illness and death. | | |
| A2 | can relate a healthy lifestyle to organs of the body and specify the location of the organs in the body. | lungs, heart, brain | |
| | can establish connections between physical activities and the activity of organs. | breathing, circulation (frequencies) | |

| | | | |
|---|---|---|---|
| | can describe digestion (as food processing in the intestine) and excretion, also the involvement of microbes. | | Food remains in the body, digestion takes place in the body, microbes are not involved. |
| | can describe human development. | oocyte → adult | |
| | can describe how all living creatures are made up of cells. | | |
| | can explain that growth is based on cell divisions and cell enlargement. | simple cell cycle | Bodies consist of matter which is built up continuously.<br>Growth takes place (only) by means of cell division. |
| | can organize his/her own learning with the help of learning aids. | | Learning means making an effort. |
| | can specify how it is possible to protect oneself against infectious diseases. | hygiene, vaccinations | Vaccination is harmful. |
| B1 | can explain functional connections using simple models. | movement (antagonists), circulation, gas exchange, nutrient / sugar processing ("word equation" using oxygen), energetic considerations of metabolic processes (photosynthesis, cell respiration) | Blood flows in several cycles; the heart purifies the blood and loads it with oxygen. Exhaled air is bad/used air. Breathing means absorbing and releasing (only) gases. Nutrients provide energy (without oxygen or other chemical conversion). |
| | can describe essential components of cells and their function. | | Cells are empty. |

| | | |
|---|---|---|
| can explain the transfer of genetic material during mitosis. | Distribution of already doubled chromosomes<br><br>Cancer as uninhibited cell division | <br><br>“Scary” cancer |
| can provide an exemplary description of the chemical role of enzymes in metabolism. | | Enzymes are players, they split and build up. |
| can describe the female cycle and evaluate contraceptive methods. | | Continuous female fertility |
| can evaluate biological and social risks and opportunities of reproductive technology. | Artificial insemination, sperm donation, surrogate mothers, cloning | |
| can distinguish the levels of genotype and phenotype. | | Gene and trait are the same. |
| can explain the influence of genes and the environment on the development of characteristic features. | The way from a gene to a trait in the simple physiological context (gene → enzyme → trait) | |
| can explain the interaction of senses and the nervous system, and the difference between stimulus and excitation. | | Stimuli (e.g. odours, images) are passed through the nerves to the brain. |
| can explain the difference and the correlation between stimulus and sensory perception. | Stimulus (light, heat, pressure, etc.) as a trigger for arousal (electrical impulses), which is routed from the receptors via nerves to the brain or the spinal cord and further to the target organ | A sound comes from the tuning fork.<br><br>Light has a colour. |
| can assess the influence of drugs on the body. | | |

| | | | |
|---|---|---|---|
| | can explain remedies for infections using knowledge about microbes. | | All microbes are dangerous. |
| | can justify and accept that illness and disability are normal aspects of human life. | reduction of physical, psychological and social barriers against the sick and disabled | Disease and disability are abnormal. |
| B1+ | can explain the advantages and limitations of functional models. | models for respiration, blood circulation, muscle movement, stimulus/arousal | |
| | can describe interactions with the help of feedback control circuits. | | |
| | can describe specific cells in tissues / organs. | | All cells are equal. |
| | can describe and compare mitosis and meiosis and explain their functions. | process, not individual stages | |
| B2 | can explain energetic and motor skills of the muscle movement. | at the level of the sarcoma | |
| | can explain the role of ATP in the body. | | |
| | can explain the chemistry of learning. | synapse | Learning functions according to the funnel model. |
| | can explain the construction capacity of the brain. | perception, e.g. colours, sounds, meaning and sense arise in the brain | Information is received from outside, not generated, but passed on. |
| | can illustrate the interplay of the nervous and endocrine systems. | homeostasis in temperature regulation | |

| | | | |
|---|---|---|---|
| | can explain cell types and functioning through gene regulation and compartmentalization. | | |
| | can explain the replication, sequence and regulation of protein biosynthesis as well as the role of proteins in chemical processes. | | |
| | can name factors of trait formation, including epigenetic ones. | role of physiological and environmental factors in gene regulation | Genes (alone) determine characteristics and contain information.<br><br>Dominant genes "reign" over recessive ones. |
| | can describe and evaluate the possibilities of family planning. | | |
| | can explain and evaluate cloning. | | |
| | can explain and evaluate the opportunities and risks of genetic engineering. | | Green genetic engineering is "evil", red is good. |
| | can explain why eugenics does not work and therefore to be rejected scientifically and socially. | | Deterioration of the "genetic material" by increasing the number of those afflicted by "hereditary diseases". |
| | can critically assess definitions of health, disease and disability. | | Health is an ideal state that excludes illness and disability. |

## 0 4.2 Biology. Relationships between Humans and Nature: creating and preserving our environment

Adults should be able to assess and evaluate human activities in biological contexts.

| GeRRN/CoFReNS - Skills<br><br>A person at this level of scientific education …. | | Examples / explanations | Everyday ideas<br><br>which are revised when the relevant competence is reached |
|---|---|---|---|
| A1 | can name mammalian species and indicate mammalian characteristics. | | |
| | can observe animals and interpret animal behaviour.<br><br>Is aware that there exist small, invisible organisms | since emotional relationships are to be preserved, anthropomorphic concepts are also to be accepted | |
| A2 | can describe both the structure of native plants and the body forms of native animal species and their life expressions and differentiate systematic groups. | | Plants do not really live and are therefore not interesting. |
| | can specify the principles of photosynthesis. | light as a source of energy, plants produce nutrients themselves | The plant takes its food from the soil. |
| | | | |
| B1 | can describe and compare photosynthesis and cellular respiration. | the energetic connection between splitting water and water formation | Plants do not breathe (no cellular respiration in plants). |

| | | | |
|---|---|---|---|
| | can classify organisms in ecological categories. | producers, consumers, decomposers | Decomposers are meaningless because decomposition processes take place without them. |
| | can describe (mutual) interrelations in ecosystems. | | |
| | can describe dynamic processes in ecosystems and explain why there is no "biological equilibrium." | simple successions, mosaic cycles in the forest | Nature strives for an equilibrium as its ideal state. |
| | can specify basic principles of protective and creative nature conservation. | Bavarian Forest, Lüneburg Heath, tidal flats | |
| | can explain that humans play a dual role in nature as component and opponent. | cultivation and maintenance of a garden | Humans are outside of nature.<br>They intervene as "troublemakers" in nature and destroy the natural equilibrium. |
| | can explain that microbes are essential decomposers and symbionts in organisms and ecosystems. | | Microbes are insignificant or harmful. "Decomposition" occurs without living organisms. |
| B1+ | can name basic taxonomic groups. | Distinguish the major groups of organisms (eukaryotes, prokaryotes) | |
| | can assess the motives and criteria of protective and creative nature conservation | "Let nature be nature" versus care of nature reserves (e.g. scrub encroachment of heathland and moorland). Distinguishing the need for interventions in different areas | Nature must be protected from humans. |

| | | | |
|---|---|---|---|
| B2 | can describe the dynamics of ecosystems. | among other things predator-prey relationships (prey regulates the predator) | Equilibria are stable ideal states.<br>The predator regulates the prey. |
| | can explain the meaning of an ecological niche. | definition of relationship between a species and its environment | A niche is a space or place. |
| | can explain energy flows and the transport of substances (including circles) in and between systems. | ecological and organismic level | Energy circulates in systems just as do substances. |
| | can explain interactions in complex systems. | | |
| | can assess how technology can contribute to environmental protection. | using so-called "renewable energies", ecosystem management using computer models | Technology is an enemy of nature. |
| | can assess the naturalistic fallacy. | | "Natural" is good. |

## 04.3 Chemistry. Matter: how properties, structures and the use of substances are related

Adults should know about the materials in their environment in order to orient themselves, to make use of specific properties of substances, or to avert possible harm which could be done by substances to themselves and to the environment.
Note: Instead of the term "small particles", the terms "building blocks of substances" or "particles of matter" are nowadays often used, as they are more precise. These terms describe the relationship between the substance and particle levels, but as they are not yet in common use we shall stick to the conventional formulation

| **GeRRN/CoFReNS - Skills**<br><br>**A person at this level of scientific education ….** | | **Examples / explanations** | **Everyday ideas**<br><br>**which are revised when the relevant competence is reached** |
|---|---|---|---|
| A1 | can express phenomena involving solid and liquid substances in a personal everyday language, without using technical expressions. | Something can be bent, is sticky or watery<br><br>Play with different materials, cook and bake | |
| | can formulate their own descriptions of observations made on substances. | There are cold and warm substances; sand cannot swim; water likes sugar | |
| A2 | can describe phenomena involving solid and liquid substances and air appropriately using simple technical terms. | By sieving, you can sort objects of different sizes, by filtration you can separate liquids from solids | |
| | can name pairs of liquids that dissolve when mixed, or which separate again after some time. | Soluble: water and alcohol<br><br>Separation: water and gasoline | |

| | | | |
|---|---|---|---|
| | can show that air takes up space, and is not nothing. | Explain wind as moving air | Gases are equated with air.<br><br>No mass is attributed to air and other gases.<br><br>Air is considered as "nothing". |
| | can select materials suitable for specific applications. | Construction of a kite or a boat (additional technical skills required) | |
| | can interpret the labelling of hazardous substances. | Justify a given suggestion for waste disposal involving different types of paint | |
| B1 | can assign a substance to a substance class because of its properties. | Metal, salt, volatile substance, pure substance<br><br>mixture, solution | Volatile substances that evaporate cease to exist ("dissolve in nothing"). |
| | can explain the composition and meaning of the substance "air". | Approximate volume ratio of nitrogen, oxygen and carbon dioxide in air<br><br>Role of these gases in the human body and in photosynthesis | Oxygen is the largest component of the air. |
| | can explain the effect of surfactants at the substance level. | Soap is both water and fat-soluble and thus stabilizes the water-fat mixture, which would otherwise separate | |
| | can link simple material phenomena with the idea that substances consist of small particles. | Interpret the change of the states of aggregation<br><br>Interpret stronger attraction between small particles as a cause of higher boiling temperature | Substances are built up continuously. |

| | | | |
|---|---|---|---|
| | can distinguish between molecule and atom. | Water molecules are formed from hydrogen and oxygen atoms, which are connected to each other | Particles are interpreted as small portions of matter, so that material properties are attributed to them. |
| | can assign radioactivity to the atomic nucleus. | Explain that radiation is caused by nuclear decay | |
| B1+ | can assign the different types of small particles to the corresponding substance class. | Atoms in the lattice (metals), ions in the lattice (salts)<br><br>Molecules (volatile substances)<br><br>Elements (small particles or lattices of atoms of a single species), compounds (small particles or lattices of atoms of different types) | |
| | can explain solubility phenomena by means of particle structures. | Low proportion of an "insoluble" substance in a solvent (petrol in groundwater)<br><br>Effect of an emulsifier | There are completely insoluble substances. |
| | can explain chemical formulae as an abstract description of small particles. | Interpret molecular formulae | $H_2O$ is just another term for water, element symbols are abbreviations of element names. |

| | | | |
|---|---|---|---|
| | can explain the periodic table (PSE) as a table of atomic species with the structure of the atomic shell as the ordering principle. | All existent small particles of substances are composed of atoms from the PSE.<br><br>An atomic shell is formed from certain numbers of electrons of the same energy. | Electrons are small objects.<br><br>Electrons can already be somewhere before a measurement is carried out.<br><br>Electrons circle around the nucleus at different distances. |
| | can formulate scientific questions on statements about material hazards. | Hazard potential of pollutants of different concentrations in food, water or air | |
| B2 | can assign macromolecules as small particles containing natural substances and synthetic substances and can describe their function. | Functions of proteins in the human body<br><br>use of plastics for saving weight and cost | |
| | can explain substance properties as a result of chemical bonding and interactions between small particles. | High temperature resistance of substances with lattice structures or with large, cross-linked molecules | Particles themselves have the property of substances.<br><br>A particular portion of any substance always shows the same temperature change when the same amount of thermal energy is supplied. |
| | can interpret different representations of molecular structures. | Structural formulae, semi-structural formulae, molecular models | |
| | can understand the classification scheme for substances in organic chemistry. | Order according to functional groups present | |

| | | | |
|---|---|---|---|
| | can assess risks and benefits of substances. | The meaning of the statement "is carcinogenic" | Carcinogens always cause cancer when one comes in contact with them. |

## 04.3 Chemistry. Chemical Reactions: What do we mean by ”A new substance is formed“?

An adult should know that a chemical reaction does not always occur, when substances are heated or mixed. He should recognize chemical reactions as processes in which a new pure substance is formed and in which energy is converted from one form (e.g. chemical) into another form (e.g. electrical). He should know that in chemical reactions the total mass of all substances involved never changes, even if gases are involved.

| GeRRN/CoFReNS - Skills<br><br>A person at this level of scientific education …. | | Examples / explanations | Everyday ideas<br><br>which are revised when the relevant competence is reached |
|---|---|---|---|
| A1 | can describe processes in which material changes occur. | Burn a sparkler, dissolve an effervescent tablet<br><br>Melting ice and snow, dissolving sugar in water<br><br>No conscious distinction between chemical reactions and changes in the state of a substance | Material changes are not commonplace. |
| | can start simple reactions and show that a material change has occurred by comparing the properties of educt and product. | Add the effervescent tablet to water, call the resulting gas a new substance<br><br>Light a candle, recognize the wax as a substance that diminishes | Substances are always preserved. |
| | can describe thermal energy and light-emitting processes. | Combustion, hand warmer | |
| A2 | can use processes involving material changes, taking possible dangers into account. | Build a campfire, light it, and extinguish it with water (without theoretical justification) | |
| | can monitor and explain substance conversion in everyday life. | Changes of the properties of substances can be recognised, e.g. colour changes during roasting, odour changes during fuel combustion in a car | Chemistry takes place only in the laboratory. |

| | | | |
|---|---|---|---|
| | can distinguish processes according to different temperature changes. | Temperature decrease when dissolving effervescent tablets,<br><br>temperature increase when quicklime reacts with water. | |
| B1 | can define the importance of fuel, oxygen and ignition temperature for the breakout of a fire and explain measures for extinguishing the fire. | All three conditions must be met for a fire to start.<br><br>Thermal energy can be used only from the system fuel/oxygen. | Energy is part of the fuel and is emitted during the its combustion. |
| | can explain the prerequisites and dangers of incomplete combustion. | In the case of fire in enclosed areas, a poisonous gas is formed due to lack of air. | |
| | can draw conclusions about products of combustion from information on the fuel. | E.g. with gasoline: carbon dioxide and water, with hydrogen: only water.. | Burning leads to the destruction of a substance, without a new substance being formed. |
| | can explain chemical reactions as the formation of new small particles (product particles) from the educt particles. | | Educts are still contained in products (as in a mixture). |
| | can apply the law of conservation of mass. | Calculation of the carbon dioxide emission of a combustion engine | When gases are formed, the reaction mixture becomes lighter. |
| | can give an example of a reaction in which the environment cools down. | Dissolve an effervescent tablet in an open system | Chemical reactions always produce energy. |
| | can explain that energy conversion always depends on a process and its conditions, not on the substance alone. | | Coal, oil and natural gas are forms of energy. |

| | | | |
|---|---|---|---|
| | can name technical devices in which chemical reactions take place in order to supply energy and can distinguish the forms of energy used. | Batteries, accumulators (electrical energy)<br><br>combustion plants (thermal energy)<br><br>rocket propulsion, explosives (mechanical energy) | |
| | can recognize from a given simple reaction equation (reaction symbol) that a chemical reaction is being described. | Explain formulas and symbols: starting material(s)/educt(s), reaction arrow and end substance(s)/product(s) | |
| B1+ | can distinguish chemical reactions from the formation of mixtures by means of the law of definite proportions. | The mixing ratio can be selected as desired, whereas in a chemical reaction, all substance portions that are involved in this process are in definite proportions, regardless of the amounts involved. | If a prepared mixture reacts, nothing at all of it remains. |
| | can explain chemical reactions at the level of the small particles of the substances involved. | Break down chemical bonds and form new ones, this normally goes hand in hand with a change in the small particles and their structure but a conservation of the mass. | |
| | can recognize and understand a process by means of a simple reaction equation. | Photosynthesis equation: formation of two substances (oxygen and glucose) from carbon dioxide and water in certain ratios | Reaction equations and formulae are the same. |
| | can explain chemical reactions in terms of the formation of new small particles from the educt particles, taking into account the fact that in chemical reactions atoms are neither completely destroyed nor newly created completely. | In the combustion of magnesium, oxygen atoms are converted into oxygen ions (oxide ions), the atomic species is retained, and the atom is not completely destroyed. | Substances and atoms remain (unchanged) in the products. |

| | | | |
|---|---|---|---|
| | can describe the effect of a catalyst. | Autocatalyst for the quick reaction of exhaust gas components to give less toxic substances | |
| | can name technical systems that do not absorb the energy required for the process in the form of thermal but of electrical energy, whereby thermal energy also always escapes into the environment. | Charging of batteries, ageing of batteries<br><br>Electrolysis | |
| | can name technical systems in which reactions take place which emit electrical and thermal energy. | Fuel cells, power stations | |
| | can explain that energy is always required for the cleavage of a chemical bond, and energy is always released during its production. | If hydrogen and oxygen react with each other to form water, energy is needed to cleave the chemical bonds in the hydrogen and oxygen molecules; energy is released in the formation of the bonds between H and O atoms in the water molecules. In this case the energy release is higher. | Chemical bonding requires energy. This is then in the bonds and can be used by their cleavage.<br><br>Chemical bonds are only found in molecules. |
| | can explain the causes of different reaction velocities of chemical reactions. | Influence of temperature and concentration (pressure), surfaces, material distributions | |
| B2 | can interpret simple chemical reactions in general as acceptor-donor processes between particles of the substances involved. | Acid-base reactions<br><br>redox reactions | |
| | can write simple chemical equations to describe chemical reactions. | | |
| | can exemplify chemical equilibria and the possibilities of influencing them. | Composition of the contents of a bottle of champagne before, during and after opening. | Reactions always run either completely or not at all. |

| | | | |
|---|---|---|---|
| | can explain processes occurring in galvanic cells and electrolysis as redox processes with energy conversion. | Principle of providing electrical energy by a battery. | |
| | can explain that the energy delivered during a reaction can be electrical or thermal, depending on the reaction conditions. | Galvanic elements versus “one-pot” reactions involving the same substances. | |
| | can explain the concept of the synthesis of macromolecules. | Reactions between molecules of one (or a few) sort(s), each of which has two or more reactive sites, lead via the formation of chemical bonds to the formation of very large molecules (macromolecules). | |
| | can decide, when comparing several synthesis options, which leads to as many atoms as possible from the starting substances being contained in the desired product, thus explaining an aspect of sustainable chemistry. | Waste products formed are minimized (the concept of atom economy). | |
| | can present the basic principles of selected chemical-technical processes and syntheses (examples: the Haber-Bosch process, petroleum refining process). | The raw material for fertilizer production (ammonia) can be manufactured on an industrial scale from easily accessible substances such as air and water or natural gas; large amounts of energy are however required.<br><br>Petroleum must be chemically treated and modified in order for various applications to be possible. | |

## 04.4 Physics. Matter: from the very large and the very small

We can use physical experimentation and reflection to extend the range of view from the very large, for example cosmology, to the very small, such as quarks. The results obtained in this manner have vastly expanded our understanding of the world, for example via the ideas of relativity and quantum physics. Both epistemological questions and the methods of acquiring knowledge play an important role in developing a personal view of the world.

| **GeRRN/CoFReNS - Skills**<br><br>**A person at this level of scientific education ….** | | **Examples / explanations** | **Everyday ideas**<br><br>**which are revised when the relevant competence is reached** |
|---|---|---|---|
| A1 | can playfully and curiously observe and explore the world around them. | Building dams or huts, to be creative using simple tools | |
| | can present their observations in their own language. | Whenever leaves move, wind blows; my shadow always follows me. | |
| | can invent their own classification systems. | Sort things found in nature using one's own criteria | |
| | can relate subjective theories based on their own observations. | Stones sink in the water because the water sucks them down, or bubbles rise in the water, because the air above the water attracts them. | |
| A2 | can show in experiments how objects change due to external influences. | Thermal expansion and contraction, compressibility of gases, liquids and solids, magnetization, electrical conductivity, changes in aggregate state | |

| | | | |
|---|---|---|---|
| | can discuss phenomena in the world around them which are caused by external influences and describe these in appropriate everyday language. | Airbeds in the sun, expansion joints, bridge bearings, explosive effect of frozen ice, compasses | Objects show "human" behaviour. |
| B1 | can deal with typical units for basic quantities in everyday life. | Density, mass, volume | |
| | can specify that atoms and other particles can be described using quantum physics. | Quantum-physical model of the atom in picture form | Atoms are really beads. |
| | can name phenomena which have only been discovered as a result of advances in atomic and nuclear physics. | Radioactivity, nuclear fusion, nuclear power stations, X-ray machines | Nuclear energy is a "clean" energy. |
| B1+ | can name methods or research facilities which made the findings of physics on the structure of matter possible. | Particle accelerator, spectral analysis | Particle physics is only of interest to the physicists themselves and has no significance for technical progress. |
| | can present historical and epistemological reflections on the structural model of matter. | Historical development of models and conceptions, future model development, connection of model and reality | |
| | can establish qualitative balances on the basis of mass-energy equivalence. | Nuclear fusion as a source of energy of the sun,<br>nuclear energy | Mass is always maintained. |
| | can understand conclusions on the structure of the cosmos and the processes taking place there. | Calculation of planetary orbits<br>development of stars. | The cosmos is eternal and static. |

| | | | |
|---|---|---|---|
| B2 | can explain methods using advanced physical concepts which made possible the findings of physics about the structure of matter. | Basic design of nuclear research reactors or fusion reactors, evaluation of light spectra, double-slit experiments with light, electrons and molecules | |
| | can properly represent the quantum physical model of the atom using more specific physical terms and appropriate concepts. | Probabilities of occurrence of electrons, natural oscillations comparable to CHLADNI sound figures, non-continuous transitions | Electrons are like very small "objects"; they are located at a certain point independent of the measuring process. |
| | can properly represent the principles of quantum physics and the theory of relativity using more specific physical terms and appropriate concepts. | Principles of quantum physics and relativity theory, standard particle model | In physics, there is nothing more to explore or discover. |
| | can present historical and epistemological considerations. | Different cosmological world models, different interpretations of quantum physics | |

## 04.4 Physics. Theory: making nature calculable

Due to its mathematical character, mechanics has historically become a prototype of modern science. The expansion of classical mechanics by relativity theory and quantum mechanics has given a new meaning to the concepts of space, time and determinism, which are fundamental to our understanding of the world. The limits of the calculability of natural phenomena have come particularly in focus because of chaos research.

| GeRRN/CoFReNS - Skills<br><br>A person at this level of scientific education …. | | Examples / explanations | Everyday ideas<br><br>which are revised when the competence is reached |
|---|---|---|---|
| A1 | can move in space and time. | Climbing, cycling | |

| | | | |
|---|---|---|---|
| | can swing and seesaw. | Swinging faster and slower, establishing balance | |
| | can specifically influence the movement of objects. | Playing skittles, throwing or kicking a ball | |
| | can describe the experiences of movement in his/her own language. | | |
| A2 | can describe the balance on a seesaw using a simple form of the lever principle. | Levers for everyday objects: pliers, scissors, car lifts (no use of formulas involved) | |
| | can solve simple equations involving uniform movement. | Distance, speed (considered as an independent variable) | |
| B1 | can describe suitable mechanical phenomena by means of the physical quantities of speed, power, momentum, energy and can calculate simple examples using a collection of formulae. | Power or impulse absorption as the cause of speed change, interplay of forces during movements | Power is something that you have. |
| | can describe pulley, bicycle and car gear systems as examples of "power converters". | | Energy can be saved. |
| | can explain the acceleration of missiles and the flying of birds and airplanes with the help of the recoil principle. | | Rockets push themselves off the ground. |
| | can use the example of impacts to describe impulse and energy conservation qualitatively. | Changes in the speeds of vehicles involved in a collision | |
| | can relate rules of conduct for road safety with physical laws. | | |
| B1+ | can analyse more complex movements kinematically. | Video analysis, motion equations | |

| | | | |
|---|---|---|---|
| | can compute more complex motion processes such as impacts using a collection of formulae. | Energy conservation, impulse conservation | |
| | can demonstrate the limits of the computability of natural phenomena using the example of selected chaotic processes. | Air and water currents, weather, cubes | |
| | can name predictable and incalculable processes in the world around him/her. | Planetary motion, friction-free fall, weather forecasting, personal disease risk | Everything is predictable if you know enough. |
| B2 | can analyse mechanical vibration phenomena and calculate them using a collection of formulae. | | |
| | can describe the principles of relativity theory and quantum mechanics by means of examples. | | Space and time are fixed, predetermined conditions.<br>Electrons, atoms and molecules can be imagined as very small beads. |
| | can understand the effects of relativity theory and quantum mechanics on the questions of predictability and computability of physical events. | Tunnel effect, modern image of atomic structure, uncertainty relation | The world can be clearly separated into subject and object ("Cartesian cut"). |

### 04.4 Physics. Energy: the supply of electrical energy in everyday life

We can no longer imagine a life without a secure supply of electrical energy. A sound physical knowledge about the energy question is indispensable In order to be able to participate in the social discussion of the future of electricity generation and to make one’s own decisions in a responsible manner.

| GeRRN/CoFReNS - Skills<br><br>A person at this level of scientific education …. | | Examples / explanations | Everyday ideas<br><br>which are revised when the relevant competence is reached |
|---|---|---|---|
| A1 | can deal appropriately with liquids in everyday life. | Building dams, building streams, letting water run through pipes, funnels, etc | |
| | can deal appropriately with electrical devices and facilities of daily life. | Electrical lighting, connecting electrical equipment with plugs, flashlight, changing batteries | |
| | can behave in such a way that "electricity" is used responsibly and economically. | | |
| | can represent the dangers of dealing with electricity in childish language. | | |
| A2 | can perform experiments using simple circuits. | Motors, solar cells, switches, batteries | |
| | can describe the structure of a bicycle lighting system. | Interactions between dynamo, wiring, and lamp / LED | |
| | can describe the power supply in the house. | Model circuits involving simple components | |
| | can describe the dangers of dealing with electrical experiments. | Use of batteries and insulated cables, but not power outlets | |
| | can illustrate examples of electrical energy storage. | Smartphones, bicycle lights with a steady mode, E-bikes, electric cars | |

| | | | |
|---|---|---|---|
| | can demonstrate that there must be energy suppliers as well as energy users. | Batteries, solar cells, dynamos, power stations. | |
| B1 | can recognize electrical circuits as systems and describe them. | | The whole is only the sum of the individual parts. |
| | can distinguish and interpret the physical quantities of electrical current, electrical voltage, electrical energy and electrical power. | Can specify and define the essential units A, V, J, W | Electricity is consumed. |
| | can use an energy cost meter (power meter) correctly. | | |
| | can compare the energy efficiency of different lighting techniques. | | |
| | can explain the importance of generators and transformers for the supply of electrical energy. | | |
| | can describe the supply and storage of electrical energy and the necessary energy conversion processes. | | |
| | can identify and compare different sources of energy for the supply of electrical energy, both at home and globally. | Thermal power plants, solar power plants, wind farms, biogas plants | At home, electricity consumption is measured. |
| B1+ | can explain the distribution of electrical current and voltage in branched electrical circuits and can make simple calculations using a collection of formulae. | | It is always the same amount of electricity that flows when the energy source is the same. |
| | can describe electrostatic phenomena in the world around him/her physically. | Carpets, lightning | |

| | | | |
|---|---|---|---|
| | can distinguish between electric charge carriers. | Electrons, ions | |
| | can compare various systems for supplying electrical energy and mobility and evaluate them, also quantitatively. | Various energy scenarios, cars with combustion engines, fuel cells, electric drive | |
| B2 | can describe electrical energy transmission systems in detail. | Electrical and magnetic fields as energy storage media, electromagnetic waves for energy transmission | Electrical energy is in the electric charge, it is carried by particles as in a rucksack. |
| | can properly classify hazards associated with electromagnetic energy transfer. | Electrosmog | |
| | can properly describe and evaluate electrical power supply systems using suitable physical and quantitative principles. | Construction of electrical power supply systems, network stability, problems due to the non-continuous availability of so-called regenerative energy carriers, storage systems | |

# 05

# Promoting Education: changing learning and teaching in the natural sciences

This chapter of the GeRRN/CoFReNS is intended to provide an impetus for a change of perspective which will make learning and teaching in the field of natural sciences more effective. On the one hand, some well-known proposals for teaching will be incorporated; but on the other, some former ways of thinking will be abandoned in order to reinforce education in the field of natural sciences; this is vital for the understanding of today's scientifically oriented world and for the solution of future problems. It therefore involves the sustainable implementation of the objectives listed in Chapters 02 to 04 of this proposal for a Common Framework of Reference for the Natural Sciences (GeRRN/CoFReNS). All types of schools and other educational institutions will be considered in the following discussion.

## 05.1 The current situation and previous attempts to change it

*The situation*

For many decades, there have been many national and international complaints, not only among experts, that learners largely lose their initial interest in scientific issues and in working in science and technology in the course of their school career. After 7 to 10 years of schooling, the subjects of chemistry and physics are among the most unpopular, although children in primary schools show a consistently high motivational approach to topics involving natural sciences.

One must therefore assume that curricula taught in secondary schools standards confront students with challenges which they are often unable to cope with or which do not arouse their interest. Internationally, the problem of the declining interest in science was already recognized as early as the 1960s. The term "swing from science" appeared in research publications (DEINTON, 1968); this trend also included countries which performed comparatively well in major educational studies (OSBORNE, SIMON & COLLINS, 2003, LYONS, 2006). In Germany no regular studies and statistical analyses of the performance of the education system were carried out until the end of the last century. On the basis on the TIMSS study conducted in 1995 (Third International Mathematics and Science Study) for the intermediate level, and the PISA studies carried out every three years from 2000 onwards, German students did in fact show continuously increasing achievements in the field of science in the most recent studies. However, the proportion of pupils found at the two lower levels of competence is still critical.

*Studies of interests and attempts to remedy the situation*

1. Attempts to increase the attractiveness of science education have been numerous. Corresponding programs, such as the Nuffield courses in England and the PSSC physics courses (Physical Science Study Committee, 1956), aimed at supporting the self-regulated learning of the students and building on their current interests. However, these and other approaches had little effect in the desired direction. Attempts to make science-based instruction more interesting by making methodological-didactical efforts without fundamentally re-thinking the structure of curricular content and the perspective of the learners did not lead to the desired success (KRAPP, 1992, p. 756).
   As a result of these findings, projects have begun in various countries to implement curricula which are closely related to the world around the learners (e.g. England: Salters Chemistry/ Physics/ Biology, USA: Chemistry in

the community, Germany: Chemistry/ Physics/ Biology in context). The results so far are indeed encouraging in terms of the impact of this kind of curricula on the interest of the individual learner as well as his/her cognitive development (e.g. PARCHMANN, GRÄSEL, BAER, NENTWIG; DEMUTH & RALLE, 2006; DEMUTH, GRÄSEL, PARCHMANN & RALLE, 2008), but they do not as yet allow us to draw distinct conclusions. However, it must be taken into account that context-oriented teaching adheres (and has to adhere) to the respective curriculum and usually does not significantly reduce the abstract nature of the formal learning topics, terms and concepts.

Surveys (for example OSBORNE & COLLINS, 2000, p. 5) have shown that a high social significance is attached to findings in natural sciences and technology and that this should also be reflected in the school curriculum. However, for more than twenty years there has been an urgent necessity, nationally and internationally, to reform teaching in the natural sciences. We therefore call for a change in the way that science is learned and taught. One prerequisite for this is an advanced (re-)structuring of the curricula and of learning processes; this should be oriented towards the developmental skills, previous experiences and interests of the learners. In addition, teaching itself must also be looked at anew.

## 05.2 Consequences

Since it has not yet been possible to significantly improve education in the field of natural sciences, we propose to adopt a change of perspective and to look more closely at the *process* of education in order to draw conclusions for the learning and teaching of the natural sciences.

### *The Change of Perspective*

Any teaching process can only succeed if it is taken into account that there is always a relationship between the teacher and the learner on the one hand and between the learner and the object to be taught on the other (Figure 2).

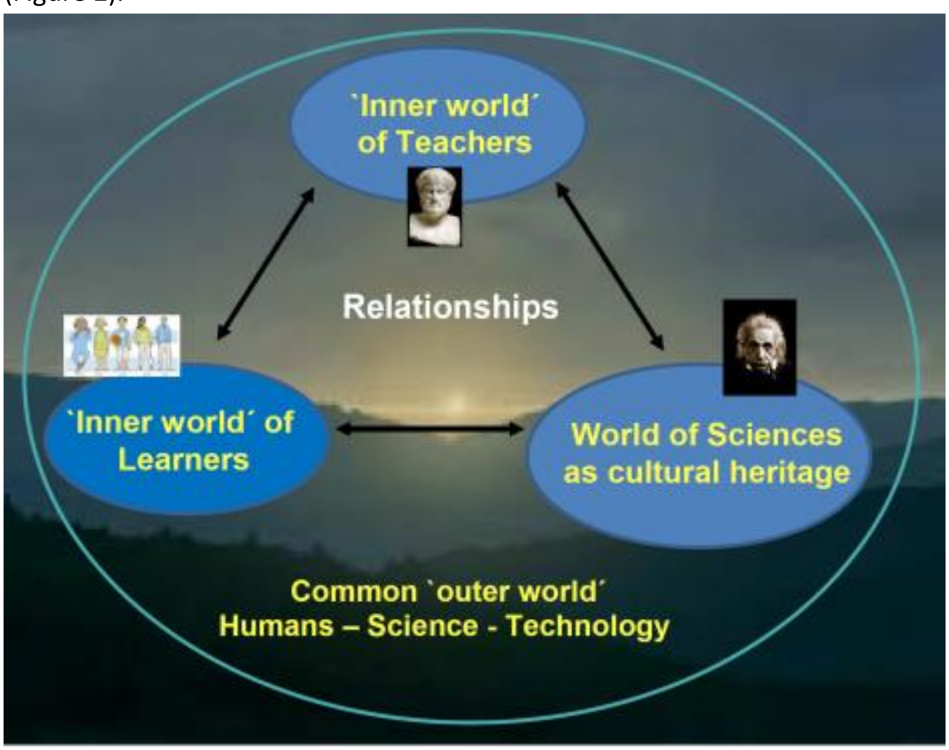


Fig. 2. Relations in teaching, presented in a modified educational triangle

For education in the natural sciences to be successful, at least four different "worlds" should be considered equally, be differentiated and linked in the education process:

1. the *"outer world"*, the common world around the teachers and learners
2. the *"inner world"* of personal experiences, personal knowledge and thinking of the *learner*
3. the *"inner world“* of personal experiences, personal knowledge and thinking of the *teacher* and
4. the *"world of natural science”*, a man-made cultural heritage.

It is therefore not sufficient to subject the experiences and concepts of the individual natural sciences to adaptation and didactic reduction. The aim of "rethinking" is to consistently take into account the "inner world of the learner" in all educational considerations. It is not simply the structure and the contents of the natural sciences themselves that is the focus of attention. We need to take into account on an equal basis the learner’s knowledge and understanding of the world as well as his/her current cognitive structures, personal experiences, knowledge of everyday life and understanding of natural phenomena and technology. Thus the basic theories of developmental and cognitive psychology move increasingly into the focus of teaching and learning (PLAPPERT, 2016). However, such a view of the learning requirements and learning processes makes it necessary to immerse oneself much deeper into the world of ideas of the learners, as HATTIE (2009) formulates:

*"the major argument in this book underlying powerful impacts in our schools relates to how we think! …* teachers and school leaders who develop these ways of thinking are more likely to have major impacts on student learning.” (HATTIE, 2009, p. 159 f., German edition: HATTIE, 2014, p. 14)

If this does not happen, learners can feel cognitively overwhelmed and thus resign and turn away from natural sciences, often for the rest of their lives.

Paying much more attention to how students think is the basis of “educational reconstruction” (KATTMANN, DUIT, GROPENGIEßER & KOMOREK, 1997; DUIT, GROPENGIEßER, KATTMANN, KOMOREK & PARCHMANN, 2012). One important conclusion of their research is that even if this process shows that that the conceptions of the learners differ from specialist findings and concepts, they are not to be regarded as "misconceptions". They must rather be considered as learning preconditions which must not be neglected. After all, they have matured in the learner, perhaps over many years, in the course of everyday experience and have thus obtained their own, individual importance for him/her (DUIT, 1993, 2009, HAMMANN & ASSHOFF, 2014, KATTMANN, 2015).

All learning takes place only on the basis of and in the context of what has been already learned and individually experienced. This can indeed be revised (reconsidered), but not easily replaced. In the process of educational reconstruction, subject-related statements and conceptions of the learners are systematically related to each other in order to shape teaching in such a way that fertile and sustainable learning is promoted. The knowledge of the perspective of the learner enables the teacher to recognize which obstacles and chances, and which ways of thinking need to be considered in subject-related learning. It should be noted that there is no easy way from the conceptions of the learners, which arise from the world around them, to scientific conceptions. The process of *"conceptual change"* should not be understood as a simple replacement of everyday conceptions by scientifically sound conceptions. Instead, the teacher should always be aware that learners have previously lived quite well with their ideas and were also mostly satisfied with them. Therefore, we should build on these ideas in order to use them for a meaningful learning of scientific concepts (conceptual re-learning, conceptual reconstruction).

In addition, schools and non-school institutions have the task of providing an educational concept which promotes attitudes that are closely associated with science both as part of the holistic cultural heritage but also of enormous importance beyond this. Above all, this includes accuracy, honesty - also regarding the limits of scientific possibilities - and the desire to recognize and understand relationships. These are indispensable for gaining knowledge and for the ability of the learner to evaluate social issues (SCHAEFER, 2007).

***Education Stages: Different Penetration Depths***

The educational process must reflect the development of the learner as a whole, from early childhood to adulthood. Regardless of the maturity of the learner, he or she should have the opportunity in any learning situation to be open to the phenomena of the world around him/her in order to be able to "connect" with them, i.e. to enter into a personal relationship, also at an emotional level. Depending on their personal cognitive possibilities and interests, the learners should be guided more or less far toward scientific conceptions and concepts, so that they can gradually integrate them into their personal conceptual network. They thus have the opportunity of moving from a superficial to a deeper structure of knowledge, i.e. to a deep understanding of scientific interrelationships. In this way, the emotional-psychological aspects which influence the affective attitudes of the learners are also taken into account. The pleasures of working with a learning object affect the appreciation of the subject matter, the increase in knowledge and the willingness to deal more closely with the relevant issues (AINLEY & AINLEY, 2011). This kind of teaching should lead to an improvement which not only lead to a better general education in the natural sciences, but also encourage especially gifted and interested pupils.

***Education as a Process***

The prerequisite for successful education in the field of natural sciences is that both the teachers and the learners take *an inquiring approach*. Thus, the teachers can reconstruct their own ideas and the "inner world of the learner" in a continuous process, repeatedly, in direct contact and in dialogue with the learners. In such a process, instead of a "culture of quick answers", a "culture of questions" needs to be established, which demands patience and perseverance from the teachers and learners and in which provisional answers also have a place. This questioning attitude is of general importance and is the prerequisite for a self-directed approach to life.

A further basic assumption is that education only then reaches the deeper structure of knowledge of the learner when the learner can describe his experiences and the topics dealt with properly *in his own everyday language*. This leads to a first comparison of new with already-present ideas. Learners are then able to compare and combine the new concepts in natural science obtained in school with their own personal preconceptions.

Everyday ideas - usually interpreted as learning difficulties - can be used specifically for teaching purposes by means of educational reconstruction of the learning contents (KATTMANN, 2015, 2017). Depending on their nature, this can be done in four different ways:

– Points of reference: an aspect is found in the learner‘s everyday conceptions which corresponds to a subject-based one and thus offers a point of reference for reaching scientifically appropriate conceptions. For example, the concept of "energy consumption" can be linked to the idea that energy is flowing through a system. "Consumption" is replaced by "intake and emission "; then, depending on the teaching goal, one comes to the concept of entropy generation or of the so-called energy degradation.

– Supplementation using a different viewpoint (change of perspective): the viewpoint of everyday life is supplemented by a different one, which revises everyday ideas, showing them in a new light. Thus, the everyday idea of substances as "energy carriers" requires the addition of the reactant oxygen, which is initially neglected, since it is not visible. Thus, the energy initially attributed to only one reaction partner is recognized as a reaction energy, which so becomes available only by the chemical reaction involving both the reaction partners.

– Contrast: the scientific idea is clearly contrasted to the everyday idea. This approach can lead to a cognitive conflict. Scientific examination shows that the electricity meter which we know from everyday life does not measure electrical current, but the electrical energy used. The electric current is always the same in the forward and return wires.

– Bridge: at times, preconceptions even open up the chance of reaching more appropriate solutions than if they were not present; sometimes we can even recognize deficiencies. Thus, the tendency of the learners to classify organisms according to their habitats leads to the revision of the pre-Darwin classification according to characteristics and to its replacement by concepts of genealogical communities whose evolution is ecologically driven.

This type of education in the field of natural science takes time. It therefore requires concentration on fundamental examples, by means of which the learners come to recognize elementary relationships and principles and to gain insights. Only after this a productive approach to "basic concepts“ is possible.

Lessons are also more effective if the learners are taught in a developmentally appropriate manner. For example, mathematization in physics, the clear distinction between substance and particle level in chemistry, and the molecular level in biology are much more comprehensible in the later stages of schooling than in the earlier ones. Learners can comprehend and digest these concepts much better if they are not taught too early, when their teaching will often involve a great deal of time spent on exercises (though these are still not really understood). Teachers must never be content to introduce concepts and facts by means of learnable but ‘empty’ phrases, such as technical terms that are not understood. The terms covered must be "alive", i.e. one can learn them conceptually in such a way that they are clearly linked with meaning. It should be noted that technical terms are part of the scientific heritage and that their "naming" is often ambiguous, and may even lead to misunderstandings when they are interpreted by the learners in their (everyday) language. Thus the "bond energy", for example, is chemically not an energy that binds parts of the molecules together but the energy that must be used to break the bonds between them. The "electric current" does not mean the "strength" or power or velocity of the electric current, but only the amount of electric charge flowing through a specific cross-sectional area in a unit of time. Likewise, the term "ecological niche" does not refer to any three-dimensional space but to the environmental relationships of a certain species of living beings. Technical terms used as words on their own do not yet convey meaning. The learners should first be able to experience and to get to know the meaning or the technical contents of a concept, so that the concept (the mental construct) is available internally to the learner before being described in a further step using the relevant scientific term.

The following thus applies: "First the concept, then the word". For the learning process to make maximum sense it should also be presented using a context-oriented design of the lessons (*situated learning* [e.g. BROWN, COLLINS & DUGUID, 1989]; *Resonance Pedagogy* [ROSA & ENDRES, 2016]).

It is possible to define several intermediate stages between simply experiencing the natural world and the ability to deal with differentiated conceptions and ideas of the natural sciences and their applications, as explained in chapter 02. For learning and teaching, it is important to realise that learners need to pass through all these stages, starting with the experience, in order to be able to deal really competently with scientific conceptions. In an initial phase, any new content should provide the learner– including mature students – with the opportunity of experiencing the learning topic in order to give it a personal meaning. It is important to understand that not every learner can achieve the greatest penetration depth in all the subjects taught. While some are capable of mathematical abstraction, others grasp the situation graphically (cf. Forms of Representation, BRUNER, 1960). This should be taken into account accordingly when making assessments of performance and evaluating progress.

## 5.3 Discussion of educational content on the basis of GeRRN (CoFReNS)

An important instrument for the implementation of the suggestions and ideas presented in this paper are the proposals made by us in Chapters 2 to 4 for a precision of the European Qualification Framework (EUROPEAN COMMISSION, 2007)[4] for the natural sciences. These specifications should now be discussed across Europe in order to provide the broadest possible common foundation for education, as is already the case for the Common European Framework of Reference for Languages.

In order to get closer to the desired goal of effective science teaching, a detailed and sometimes painful discussion of content is inevitable. The present reference framework GeRRN/CoFReNS can be of great use in carrying out this task. A central criterion for the selection of teaching content must not be their present role in teaching in schools, but rather the question of whether they are suited for the promotion and stabilization of the competences presented in the GeRRN/CoFReNS.

## 5.4 Looking ahead: conclusions for learning and teaching in the natural sciences

As in any subject, the learning and teaching of natural sciences can only be achieved on the basis of a mutual understanding between learners, teachers, and learning topics. This results in the following postulates:

- It is not enough to refine or reduce the natural science content educationally.
- It is important to build bridges between the "learner's world of learning" and the "world of natural science". It is essential for teachers to deal with the currently present cognitive structures, personal experiences and everyday knowledge.
- The learner must be given time and opportunity to talk about and reflect on his ideas, so that steps towards sustainable concepts are more successful.

[4] Six years ago there was a proposal to set up such a normative setting and to rethink teaching in English-speaking countries (HARLEN, 2010).

- It is not helpful to want to teach students how to deal with abstract concepts and models if they are not yet ready to deal with them.
- Learners must be given the opportunity to understand subject matter gradually, from experiencing a phenomenon to dealing with it more and more systematically and finally reaching an understanding with conceptual precision or mathematization.
- It requires an exploratory attitude of the learners and the teachers, i.e. a culture of questioning instead of a culture of rapid answers.
- The content of the scientific subjects must be chosen in such a way that the competences listed within the framework of the GeRRN/CoFReNS are firmly established at the various different levels of knowledge.

Rethinking education in the natural sciences is of particular importance at the present time. When decisions which significantly affect society are taken on the basis of undifferentiated considerations, emotions, and uncritically accepted slogans, then society itself is in danger. Europe's future viability is heavily dependent on technical developments, and these must be supported by the considered acceptance of the public. This is however only possible when a wide and thorough understanding of natural sciences is present, which is based on a constructive, critical and positive attitude to science and technology. How can democratic decision-making processes for the introduction of alternative technologies otherwise be carried out, and how can we be sure that a sufficient number of young people will choose professions with a scientific and technical background?

Even although we may here be only repeating many well-known arguments, the present unsatisfactory situation of basic education will only be changed if the deficits are widely recognized and accepted as such. Only then will we have a chance to make the necessary changes and thus attain a sound basic understanding of scientific issues across the social classes. The present authors are committed to this and the MNU Association as a whole is also committed to it. Our conclusions for learning and teaching in the natural sciences apply equally to all formal and informal educational institutions. Furthermore, personal professional experience connects the authors of this paper with teaching in schools. Four of the authors actively teach a science subject at school, and all of us regularly get insights into the real education process in Germany. They are well aware that many of their colleagues are excellent teachers with a high level of commitment.

It is in everyone’s interest to increase the importance of education in our society. However, a look at the observed and measured situation of education today, and particularly science-related education, shows that the efforts made at school and other educational institutions are not sustained in the long term. We therefore see an urgent need to change both the national regulations and the design of science education in all school forms. Curriculum requirements, particularly at primary and lower secondary school level, should take much greater account of the learner's learning requirements.

If we manage to take a closer look at the personal conceptions and the cognitive possibilities of the learner, so that the students do not turn away from the natural sciences as their schooling proceeds, then we will have achieved a major goal.

## References

AINLEY, M., & AINLEY, J. (2011). Student engagement with science in early adolescence: The contribution of enjoyment to students' continuing interest in learning about science. *Contemporary Educational Psychology, 36*(1), 4-12.

BARKE, H.-D. (2006). *Diagnose und Korrektur von Schülervorstellungen*. Berlin, Heidelberg: Springer.

BROWN, J. S.; COLLINS, A. & DUGUID, P. (1989). Situated Cognition and the Culture of Learning. *Educational Researcher; 18*(1), 32-42.

BRUNER, J. S. (1960). *Der Prozess der Erziehung*. Berlin 1970; (Original Version: *The Process of Education*).

DEMUTH, R.; GRÄSEL, C.; PARCHMANN, I.; RALLE, B. (Eds.). (2008). *Chemie im Kontext – Von der Innovation zur nachhaltigen Verbreitung eines Unterrichtskonzepts.* Münster: Waxmann.

DUIT, R. (1993). Schülervorstellungen - von Lerndefiziten zu neuen Unterrichtsansätzen. *Naturwissenschaften im Unterricht Physik, 4*(16), 4-10.

DUIT, R., GROPENGIEßER, H., KATTMANN, U., KOMOREK, M., & PARCHMANN, I. (2012). The Model of Educational Reconstruction – a framework for improving teaching and learning science. In D. Jorde & J. Dillon (Eds.), *Science education research in Europe* (pp. 13-37). Rotterdam: Sense Publishers.

DUIT, R. (2009). Alltagsvorstellungen und Physiklernen. In E. Kircher, R. Girwidz, & P. Häußler (Eds.), *Physikdidaktik – Theorie und Praxis* (S. 605-630). Berlin: Springer.

EUROPÄISCHE KOMMISSION (2007). *Schlüsselkompetenzen für lebensbegleitendes Lernen, ein europäischer Referenzrahmen*. Luxemburg: Amt für amtliche Veröffentlichungen der Europäischen Gemeinschaften. Download http://www.kompetenzrahmen.de/files/europaeischekommission2007de.pdf (letzter Zugriff: 24. 07. 2017). In English: KEY COMPETENCES FOR LIFELONG LEARNING European Reference Framework. Download: https://euroclio.eu/wp-content/uploads/2016/03/YiA-Key-Competences-for-Lifelong-Learning-European-Reference-Framework.pdf

GOETHE-INSTITUT (Ed. Deutsche Ausgabe 2002). *Gemeinsamer europäischer Referenzrahmen für Sprachen: Lernen, lehren, beurteilen*. München: Online available at http://www.goethe.de/z/50/commeuro/ (letzter Zugriff: 24. 07. 2017). In English: http://www.coe.int/t/dg4/linguistic/source/framework_en.pdf

HAMMANN, M. & ASSHOFF, R. (2014). *Schülervorstellungen im Biologieunterricht. Ursachen für Lernschwierigkeiten*. Seelze: Klett/Kallmeyer.

HARLEN, W. (Ed.). (2010). *Principles and big ideas of science education*. Hatfield.

HATTIE, J. (2009). *Visible Learning -A Synthesis of over 800 Meta-Analyses Relating to Achievement*. Abingdon: Routledge.

Hattie, J. (2014). *Lernen sichtbar machen für Lehrpersonen*. Überarbeitete deutschsprachige Ausgabe, Baltmannsweiler: Schneider-Verlag.

KATTMANN, U., DUIT, R., GROPENGIEßER, H. & KOMOREK, M. (1997). Das Modell der Didaktischen Rekonstruktion - Ein theoretischer Rahmen für naturwissenschaftsdidaktische Forschung und Entwicklung, *Zeitschrift für Didaktik der Naturwissenschaften* 3, H. 3, 3-18.

KATTMANN, U. (2015). *Schüler besser verstehen. Alltagsvorstellungen im Biologieunterricht*. Hallbergmoos: Aulis.

KATTMANN, U. (Ed.) (2017). *Biologie unterrichten mit Alltagsvorstellungen. Didaktische Rekonstruktion in Unterrichtseinheiten.* Seelze: Klett/Kallmeyer.

KRAPP, A. (1992). Interesse, Lernen und Leistung - Neue Forschungsansätze in der Pädagogischen Psychologie. *Zeitschrift für Pädagogik 38*/5, 747-770.

LYONS, T. (2006). Different Countries, Same Science Classes: Students' experiences of school science in their own words*, International Journal of Science Education, 28*/6, 591-613.

MNU (2004). *Naturwissenschaften besser verstehen, Lernhindernisse vermeiden. Anregungen zum gemeinsamen Nutzen von Begriffen und Sprechweisen in Biologie, Chemie und Physik (Sekundarbereich I).* Troisdorf: Bildungsverlag EINS. Download http://www.mnu.de/images/PDF/fachbereiche/chemie/naturwissenschafen_besser_verstehen.pdf (letzter Zugriff: 02. 08. 2017).

OSBORNE, J., & COLLINS, S. (2000). *Pupils & parents views of the school science curriculum*. London: Kings College.

OSBORNE, J., SIMON, S. & COLLINS, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, 25(9) 2003.

PARCHMANN, I.; GRÄSEL, C.; BAER, A.; NENTWIG, P.; DEMUTH, R. & RALLE, B. (2006). "Chemie im Kontext": A symbiotic implementation of a context-based teaching and learning approach. *International Journal of Science Education, Vol. 28*, No. 9, 14 July 2006, pp. 1041–1062.

PLAPPERT, D. (2011). Naturwissenschaftliche Bildung vom Kindergarten bis zur Hochschulreife. *PdN Physik in der Schule* 5/2011.

PLAPPERT, D. (2016). Unterricht, der innerlich berührt – der n-Prozess als didaktischer Weg, erläutert an einer Unterrichtseinheit „Von der Schütteltaschenlampe zu den elektromagnetischen Wellen*". PdN Physik in der Schule, 6*(65), S. 40 - 45.

RHEINLAND-PFALZ (2014). Ministerium für Bildung, Wissenschaft, Weiterbildung und Kultur. *Lehrpläne für die naturwissenschaftlichen Fächer für die weiterführenden Schulen in Rheinland-Pfalz, Klassenstufen 7 – 9/10*. 2014, S. 9.

ROSA, H & ENDRES, W. (2016). *Resonanzpädagogik – Wenn es im Klassenzimmer knistert.* Weinheim: Beltz.

SCHAEFER, G. (Ed.) (2007) *Allgemeinbildung durch Naturwissenschaften mit Ergänzung*. GDNÄ, Köln.

## Authors

*BIRGIT EISNER is a teacher of physics and mathematics at the Camerloher Gymnasium in Freising and a physics expert on the board of directors of the MNU.*

*Dr. ULRICH KATTMANN is a professor of biology education of the Carl von Ossietzky University of Oldenburg (retired).*

*MATTHIAS KREMER is Division Manager of Natural Sciences and Instructor for Chemistry at the State Seminar for Didactics and Teacher Training in Rottweil and Secretary of the MNU Executive Board.*

*JÜRGEN LANGLET was a teacher of biology, chemistry and philosophy and headmaster at the International German School in Brussels until 2017. He is a former federal chairman of the MNU.*

*DIETER PLAPPERT is Division Manager of Natural Sciences and Instructor for Physics at the State Seminar for Education and Teacher Training in Freiburg.*

*Dr. BERND RALLE is Professor of chemistry education at the TU Dortmund and chief-editor of the MNU-Journal.*

Impressum

Editor:
MNU
Deutscher Verein zur Förderung des mathematischen und naturwissenschaftlichen Unterrichts e. V. (German Association for the Advancement of Mathematical and Science Teaching, registered association)

List of picture sources:
DIETER PLAPPERT

Translation:
BETTINA BEE, Rottweil, Prof. Dr. TERENCE MITCHELL, TU Dortmund

Print:
Appel & Klinger, Druck und Medien GmbH, Schneckenlohe (Germany)

ISBN 978-3-9405 16-27-5

2nd Revised Edition

Vossenacker Str. 9, 41464 Neuss (Germany)