FRAMEWORK FOR DIAGNOSTIC ASSESSMENT OF SCIENCE

Edited by
Benő Csapó • Gábor Szabó

NEMZETI TANKÖNYVKIADÓ

Framework for Diagnostic Assessment of Science

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If you cannot measure it, you cannot improve it.

Lord Kelvin

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Introduction

The motto chosen for the volumes discussing the frameworks of diagnostic measurements is a quotation by *Lord Kelvin* “If you cannot measure it, you cannot improve it”. The truth of this dictum can be illustrated by an example taken from another domain of life, the practice of medicine. If we were unable to measure body temperature, it would be impossible to ascertain the effects of medication intended to reduce fever. We could, of course, estimate body temperature without measurement by touching the forehead, for instance, but the accuracy of the estimate may be influenced by several subjective factors. The work of a doctor is simply unimaginable today without a range of measuring tools aiding the diagnosis and the choice of the right therapy. Teachers, in contrast, are still obliged to rely mostly on methods of subjective estimation in their education programs, having no access to tools of measurement of either their students’ level of development or the effects of intervention efforts or day-to-day teacher activities. The dilemma of measurement in education is also aptly summarised in a quotation, one by *Albert Einstein* this time: “*Not* everything that is *measurable* is *important*, and *not* everything that is *important* is *measurable*”. Echoing that statement, the problem we need to face with respect to the diagnostic assessment of knowledge of science can be characterised as follows: The most important elements of knowledge are not always those that most readily lend themselves to measurement. It is understandable that the earliest efforts to measure knowledge of science focused on areas that were the easiest to measure, namely students’ ability to reproduce the subject matter that had been presented to them the way it had been presented. The assessment of students’ comprehension of the subject matter and their ability to apply that knowledge to new contexts is a more complicated task. We must progress even further if we wish to assess whether science education can meet the objective of developing students’ mental abilities and scientific thinking.

Over the decades around the turn of the Millennium, a growing emphasis has been placed throughout the world on research and development programmes the integrated results of which may lead to a substantial improvement in public education if transferred into practice. The programme providing the framework for the present volume occupies the intersection of three major development trends. First, various international surveys have given a great impetus to the development of educational assessment and testing. Second, recent research results in educational sciences and psychology have led to increasingly refined understanding of the concept of knowledge, which allows more precise definitions of what should be measured at different stages of development. Third, the availability of info-communication technologies allows measurements to be performed in the way and with the frequency required by public education.

The key to progress in an education system is the availability of efficient feedback mechanisms at the various levels of that system. Such mechanisms can be created through measurements providing objective data on various aspects of performance at each level of the system. These measurements allow us to ascertain whether the education program is successful in meeting its targets, or whether a given intervention strategy has achieved the desired results. At present, feedback mechanisms operate on three main levels in public education. Feedback is provided by international surveys, which have become regular events during the past decade. Hungary has been included in the major science education surveys (PISA, TIMSS). The data allow the performance of the Hungarian education system to be evaluated in the context of other countries' results and the comparison can be used to draw conclusions with regard to ways of improving system-wide features. The results of the recurrent cycles of the surveys also provide feedback on the effects of any interventions. The international assessment programmes are planned and implemented with the contribution of the top research and development centres in the world. The various solutions of measurement methodology developed in these centres are made use of in the preparation of national assessment systems.

Several countries, including Hungary, have introduced a system of annual assessment covering all students in selected grades of schooling. These surveys provide detailed feedback to individual schools on the performance of their own students. Based on an analysis of the results, schools may improve their internal processes and the efficiency of their activities. The results are also made public, which may act as an incentive to seek ways of improvement and development. The experiences of countries where a system of this sort has been in place for a relatively long time show, however, that placing pressure on schools has the effect of improved efficiency only within certain limits. If the stakes associated with the evaluation are too high for either the teachers or the schools, various distortions may result. Further improvement in efficiency can only be achieved by devising methods and tools directly assisting the work of teachers. These include measurement tools that enable teachers to obtain a precise assessment of students' level of development in areas of key importance with respect to their further progress.

Traditional paper-and-pencil tests were, however, very costly and labour-intensive and were therefore unsuitable for performing sufficiently frequent assessments. The second important recent development is thus the explosive advancement of information and communication technologies, which offer novel solutions in every area of life, including educational measurement. Thanks to these technologies, tasks that used to be beyond solution have now become simple to implement in education also. One of these is educational assessment providing frequent diagnostic feedback. Computers were put in the service of education effectively as soon as the first large electronic computers appeared; educational computer software has been around for decades. The use of information technology in education was, however, often motivated by the technology itself, i.e., the reasoning was that now that these tools were available, it made sense to use them in education. Online diagnostic assessment approaches the question from the opposite direction: an appropriate technology is sought as a solution to the problem of implementing a task of key significance in education. From this perspective, info-communication technology is a tool that has no substitute in expanding the range of possibilities for educational assessment.

The third development, one which is closest to the concerns of this volume, is the cognitive revolution in psychology, which affected several areas towards the end of the last century and gave a new impetus to research efforts in connection with school learning and teaching. It has led to the emergence of new and more differentiated conceptions of knowledge allowing a more precise definition of the goals of public education and the development of scientifically established standards. This process has also opened the way to a more detailed characterisation of student development processes. The psychological approach penetrated early science education relatively soon. Piaget's classic works on cognitive development used simple experiments of science to study child cognition, and later research on conceptual development and misconceptions also used cognitive processes related to science phenomena as their primary domain of inquiry.

Once the special significance of early childhood had been recognised, the focus of attention shifted to the first few years of schooling, especially to the encouragement of language development and reasoning skills. Several studies have provided evidence that the acquisition of basic skills is crucial for in-depth understanding of the subject matter taught at school, which is in turn essential for students to be able to apply their knowledge to new contexts rather than just reproduce exactly what they have been taught. If the required foundations are not constructed, serious difficulties will arise at later stages of learning: failures suffered during the first years of schooling will delimit students' attitudes towards education for the rest of their lives. The development of concepts related to science begins even before the start of formal education and the first years of school play a decisive role in steering conceptual development in the right direction. Early science education shapes children's thinking, their approach to the world and their attitudes towards empirical discovery.

The developmental processes discussed above have provided the basis of a project entitled "Developing Diagnostic Assessments" launched by the Centre for Research on Learning and Instruction at the University of Szeged. The project focuses on the development of detailed frameworks for diagnostic assessments in three major domains – reading, mathematics and science – in the first six grades of school. This involves the development of question banks containing several thousand questions and exercises, which will be accessible to students on the Internet through an online computer system. The system – the implementation of which is a lengthy process involving several hierarchically organised steps – will fulfil the function of providing frequent individual student-level feedback.

The diagnostic tests are designed to assess individual students' progress relative to various reference points. Similarly to system-wide surveys, the programme allows the population average to act as a standard of comparison: being able to compare an individual's performance to the performance of their peers can provide important information. In addition to this, certain developmental benchmarks and external reference points should also be defined. The diagnostic tests should, however, go even beyond that: they should follow students' progress over time, i.e., compare performance at a given point in time with the results of previous measurements.

Diagnostic assessment can only be an efficient tool in student education if the measurement methods are based on scientifically based frameworks. Issues such as the target areas or dimensions of progress assessment, the desired direction of development, what constitutes progress in the various areas, and what constitutes advancement to the next step of development can only be decided on the basis of research evidence. Both the aim of diagnostic value and the fact that the focus is on early childhood call for a detailed specification of test contents, a well-rounded, scientifically based theoretical framework and the incorporation of considerations of developmental psychology, knowledge application standards and the discipline-specific characteristics of science education.

Frameworks define the object of measurement. Their development has been one of the most important tasks of the project. The results are presented in three uniformly structured volumes. The current volume discusses the frameworks of diagnostic assessment for science, and the two companion volumes summarise the conclusions for reading and mathematics. The development work for the three domains proceeded in parallel and the same broad theoretical framework and conceptual system were used for the development of the detailed contents of assessment for each of these domains. The three volumes therefore share not only their structure but also parts of their introduction and of one of the internal chapters. In accordance with international practice, the term *science* is used throughout the project as a general term referring to the domain of assessment.

The work presented in this volume draws on the experiences of several decades' research on educational assessment at the University of Szeged and on the achievements of the Research Group on the Development of Competencies, Hungarian Academy of Sciences with special reference (a) to the results of studies related to the structure and organisation of knowledge, educational evaluation, measurement theory, conceptual development, the development of reasoning skills, problem-solving and the assessment of school readiness; and (b) to the technologies developed for test item writing and test development. Our present work on developing assessment frameworks has benefited a great deal from the results of several specific projects, including the Hungarian Educational Longitudinal Program.

The development of the frameworks of diagnostic assessments is, however, a complex task reaching beyond the experiences mentioned above. In order to achieve our goals, extensive international collaboration was required. Our work has therefore been carried out in cooperation with a large science community including experts in Hungary and abroad. The opening chapter of each volume has been prepared with the contribution of a leading researcher in the relevant field; thus our work rests upon the scientific foundations most widely valued in the international community. The details of the frameworks have been developed with the contribution of teachers and other professionals with practical experience in test construction.

The system of diagnostic assessments is based on a three-dimensional approach to knowledge, in line with the traditions characterising the entire history of organised education. The wish to educate the intellect, to cultivate thinking and general cognitive abilities has been around as long as organised education has. Modern public education also sets several goals applying to the students themselves as individuals. In order to achieve these goals, we must first of all be guided by evidence provided by the fields of inquiry concerned with the human being and the developing child, i.e., the results of studies in developmental psychology and the psychology of learning. In the context of sciences, the focus of this dimension is the development of scientific thinking.

Another area of educational goals is related to the usability of school knowledge. The dictum "*Non scholae sed vitae discimus.*" is perhaps more topical today than ever before, since our modern social environment is changing far too rapidly for public education to be able to keep pace with it. Past research has revealed that knowledge transfer is not an automatic process; students cannot automatically apply their knowledge to new contexts. For this reason, the assessment of applicable knowledge appears as an independent dimension in diagnostic assessments. This task requires a different approach to testing: we must define what is expected of students that will enable them to apply their knowledge in different school contexts and in contexts outside of the school. The third dimension concerns the selection of content knowledge accumulated by science that public education should transmit. Not only because the above goals cannot be achieved without content knowledge but also because it is an important goal of its own right that students should become familiar with the knowledge generated by science and organised according to the internal values of science.

The above goals have been competing with each other over the past few decades with one or another coming into fashion at different times. For the purposes of the present project we assume that education integrates the three main goals in fulfilling its function but diagnostic assessments must differentiate between them. Diagnostic assessments must be able to show if there is insufficient progress in one or another of these dimensions.

The first three chapters of this volume discuss the theoretical background and research evidence pertinent to each of these three dimensions. In Chapter 1, Philip Adey and Benő Csapó discuss the role of science education in the development of thinking and the assessment goals related to this area. In Chapter 2, Mária B. Németh and Erzsébet Korom give an overview of theoretical issues related to scientific literacy and the application of scientific knowledge. Chapter 3 by Erzsébet Korom and Gábor Szabó summarises the content knowledge offered by science to the early stages of public education, especially for the purposes of the development of scientific thinking. Each chapter provides an extensive review of the literature and the included detailed bibliographies can assist future research. In Chapter 4, Erzsébet Korom, Mária B. Németh, Lászlóné Nagy and Benő Csapó discuss theoretical issues related to the development assessment frameworks, and outline a practical solution providing the foundations for diagnostic assessment programmes.

The second part of the volume contains the detailed frameworks for diagnostic assessment. The purpose of this section is to provide a basis for the development of measurement tools and test questions. Our diagnostic assessment program treats the first six grades of school as a continuous educational process. The results of assessment are therefore interpreted relative to scales spanning all six grades; students are placed along these scales according to their current level of development. The content specifications of assessment questions could also essentially form a single continuous unit. However, in an effort to allow greater transparency and to follow the traditions of educational standards, this process has been divided into three stages, each of which covers approximately two years. For the three dimensions, therefore, a total of nine content blocks are described.

In their present state, the frameworks detailed in this volume should be seen as the first step in a long-term development process. They specify what is reasonable to measure and what the major dimensions of assessment are, given the present state of our knowledge. As the domains covered develop at a very rapid rate, however, the latest findings of science should be incorporated from time to time. The content specifications can be constantly updated on the basis of our experiences of item bank development and an analysis of the data provided by the diagnostic program in the future. Our theoretical models can also be revised through an evaluation of the test questions and an analysis of relationships emerging from the data. In a few years' time we will be in a position to look at the relationship between the various areas of early development and later performance allowing us to establish the predictive and diagnostic validity of test questions, which can be a further important source of information for the revision of theoretical frameworks.

Erzsébet Korom played a prominent role in the preparation of this volume. In addition to co-authoring four of the chapters, she also led the research team developing the detailed description of the contents of the assessment. Besides the authors of the chapters, several colleagues have contributed to the preparation of this volume, for which we are very grateful. Special thanks are also due to the team responsible for the organisation and management of the project: *Katalin Molnár*, *Judit Kléner* and *Diána Túri*. The development and final presentation of the content of the volume have benefited greatly from the comments of the reviewers of earlier versions. We would like to take this opportunity to thank *Katalin Papp* and *Péter Tasnádi* for their valuable criticism and suggestions.

Benő Csapó and *Gábor Szabó*

1

Developing and Assessing Scientific Reasoning

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Introduction

Science education has always been considered to be one of the best tools for cultivating students' minds. Scientific activities such as conducting empirical research, designing and executing experiments, gaining results from observations and building theories are seen as those in need of the most systematic forms of reasoning. The fact that a deep understanding of complex scientific theories requires well-developed reasoning skills leads to the assumption that teaching sciences at school will improve students' thinking skills as well. It probably did in the case of a few students who really deeply understood science, but for the majority this assumption did not work mainly because the science was set too far in advance of students' current cognitive capability so they were unable to engage in it fruitfully.

The argument that learning sciences facilitates the development of thinking was one of the justifications for extending the proportion of science in school curricula. However, the rapid growth of scientific data and their distillation into school curricula often resulted in large quantities of disciplinary content that students were not able to process and understand. Until the second half of the twentieth century, the lack of adequate psychological theories or of evidence-based methods of assessing the effects of science education made it impossible to fulfil the ambitious goals of systematically improving students' reasoning skills.

The gap between the level of abstraction, complexity and organisation of teaching materials on the one hand, and students' actual cognitive development on the other can be narrowed in two ways. One side of the solution is that teaching materials should be better adjusted to students' psychological and developmental characteristics. This requires more information on students' actual developmental level and individualized teaching methods to support students' progress. The other side of the solution is accelerating students' cognitive development in order to elevate their level of reasoning to the requirements of the learning tasks. Research has shown that development can be stimulated by specific activities and exercises, and learning science offers a number of efficient opportunities to accelerate students' cognitive development (Adey & Shayer, 1994). Systematic monitoring of the development of students' reasoning skills may facilitate both directions of this adjustment (Glynn, Yeany & Britton, 1991).

In this chapter, first we summarise the results of psychological and educational research concerning cognitive development related to science education. Next, we systematically describe what thinking processes might be developed in science education. Then we illustrate the possibilities by introducing some of those methods which utilise these results in science education and aim at more efficient training of students' thinking processes and finally discuss how these thinking processes can best be measured, diagnosed and monitored in order to support teaching and learning.

Reasoning in Science: Cognitive Development in an Educational Context

Science Reasoning and General Reasoning

Is scientific thinking special? That is, is scientific thinking distinctly different from thinking in other subject areas? Obviously, there are some special characteristics, but to what extent are these simply particular expressions of the human ability to process information in general? Human cognition and the accumulation of experiences are often comparred to the process of scientific research and discovery. However, although there are broad analogies between the logic of scientific research and human reasoning, there are some significant differences as well (Howson & Urbach, 1996; Johnson-Laird, 2006). One of the major differences stems from the developmental nature of human cognition. Humans reach their actual reasoning capacity through a long developmental process, which is shaped by the stimuli and information one has received and processed. Although science has also reached its current form through a long developmental process, the logical system that children are expected to comprehend is a stable constant structure, while children attempting to master it may be in different developmental stages.

Certainly Jean Piaget and his co-workers regarded scientific thinking as representative of general intellectual processing, or general intelligence. During investigations of children's development of thinking from infancy to adolescence, they used practical tasks such as ordering things by size, exploring conservation, cause and effect, control of variables and probability (e.g., Inhelder & Piaget, 1958; Piaget & Inhelder, 1974, 1976), all of which would be easily recognised by mathematics and science teachers as central to their subject areas. He drew conclusions about cognitive development in general from children's performance in these apparently scientific tasks. Also, typical non-verbal tests on general intelligence such as Raven's Matrices (Raven, 1960) or the Calvert Non-verbal test (Calvert, 1986) tap into subjects' ability to use inductive and deductive reasoning which is the basis of a much scientific thinking.

On the whole, this extrapolation from scientific thinking to thinking in general has received some empirical support. Although the general stages of cognitive development described by Piaget are expressed in scientific terms, their descriptions in terms of concrete operations or abstract reasoning are easily applied across all forms of learning. Furthermore, as we will describe later in this chapter, training in scientific thinking has been shown to transfer to higher levels of achievement in remote subject areas such as native or second language learning (Csapó & Nikolov, 2009) suggesting, at least, an intimate link between science reasoning and reasoning in general.

Notwithstanding such evidence it is possible to make some distinction between scientific thinking and 'good' thinking in general. Consider this list of general thinking skills (from McGuinness, 2005):

(1) pattern-making through analysing wholes/parts and similarities/differences;
(2) making predictions and justifying conclusions;
(3) reasoning about cause and effect;
(4) generating ideas and possibilities;
(5) seeing multiple perspectives;
(6) solving problems and evaluating solutions;
(7) weighing up pros and cons;
(8) making decisions.

The first three have ready expressions within science. The fourth, that is, generating ideas, is certainly important in science, but – in a different guise – it is also central to artistic and literary creation. The fifth – seeing multiple perspectives – may be necessary at the frontiers of science for trying to integrate apparently conflicting models (e.g., wave-particle duality). However, at school level it is not as typical of science as it would be of, say, history, social studies or drama where high level thinking includes the ability to see events from a number of different perspectives. It may also be imbued with an emotional load (*can* I see the viewpoint of my enemy?) which is, at least theoretically, less common in scientific thinking. Notwithstanding, it may be important in teaching: teachers should often try to observe a phenomenon from a child's point of view in order to understand the way children reason and that they draw conclusions differently in comparison with an expert. The last three are certainly very general and apply far beyond the boundaries of the sciences. In particular 'solving problems' is something of a catch-all phrase which can embrace many activities. When, as within PISA frameworks, the idea of complex problem solving is well-characterised (OECD, 2003), it is seen as much broader than a scientific ability.

On this argument science education seems to have less to offer in the development of general reasoning ability. Yet, our final conclusion on the debate about the generality-specificity of thinking must rest on the model of intelligence that is adopted. If each of the thinking skills is relatively independent of one another, then each needs to be developed in its own right. On the basis of this model, it is possible to conceive of an individual who scores high on reasoning about cause and effect but low on decision-making. The alternative is to regard each of the individual thinking skills as expressions of a general underlying intelligence. In this case, work on developing a sub-set of whichever list of thinking skills we happen to favour should have some transfer effects to those skills not explicitly trained.

Elsewhere, (Adey, Csapó, Demetriou, Hautamäki, & Shayer, 2007) we have argued that there is indeed a general intelligence, which is amenable to educational influence offering a potential mechanism by which thinking abilities may be transferred from those trained to others. This model also posits that 'on top' of this general processor (g) there exist a set of specialised structural systems (Demetriou, 1993) which allow for a limited independent variation of different areas of thinking (e.g., quantitative-relational, spatial). A critical feature of this model is that the development of the specialised systems is both limited by and is the route into the development of the general intellectual processor and its executive control (self-regulation). We believe that there is substantial empirical evidence which is compatible with this model and that it offers a fruitful basis for educational action and for the analysis offered in this chapter.

Learning and Development

Discussing the problem of development in educational context it is necessary to clarify its relationship to learning. The distinction between 'learning' and 'development' is one about which Vygotsky was exercised at some length. Vygotsky thinks that formal education in one specific domain definitely influences development in other domains of knowledge by a sort of generalisation process… (Tryphon & Vonèche, 1996. p. 6). Indeed, the whole idea of the *Zone of Proximal Development* can be seen as Vygotsky's attempt to explain the relationship between learning and development.

Although we cannot make a sharp distinction between the two concepts, it may be possible to characterise extreme (stereotypical) examples of each term. At the limits, one thinks of 'learning' in relation to content matter and the acquisition of simple knowledge such as the correct spellings of words or multiplication tables, whilst 'development' relates to functions which unfold during a process of maturation, minimally or not at all influenced by the environment. Development is an organic process; a certain stage is based on the previous ones.

Of course, in reality there can be no such thing as 'pure' examples of learning or development in these stereotypical terms – learning uninfluenced by development, or development uninfluenced by experience. Erroneous belief in such stereotypes is at the root of much misunderstanding in education, for example, cognitive development or the unfolding of intelligence is entirely under the control of time and heredity, or that the acquisition of concepts requires only sufficient effort of learning regardless of their inherent complexity.

This problem may be illustrated by an example taken from mathematics education. Hungarian students learn how to convert hours into minutes, meters into millimetres etc. by the fourth grade with considerable effort of memorising the rules and mechanically exercising the conversion operations. Then, they pass to the next chapters of curriculum, learning of conversion ends, and they begin to forget what they have learnt. Their proportional reasoning is at a lower developmental level at that age, and learning rules of conversion has a little impact on it. Later, on the other hand, by the seventh grade they can convert measures again quite well, as it is a specific application of proportional reasoning that reaches a higher developmental level by that time (Csapó, 2003).

Several empirical studies demonstrated that learning sciences does not result necessarily in better scientific reasoning. For example, Bao et al. compared Chinese and American university students' physics knowledge and scientific reasoning. They have found that although Chinese students performed much better on the science knowledge test (attributable to their more demanding high school science studies), their performance on the science reasoning test was similar to that of their American peers (Bao et al., 2009).

It is more useful to see learning and development as lying at either ends of a spectrum, with the simple acquisition of knowledge at the L-end (but still dependent to some extent on the individual's level of maturity) and the development of general intelligence at the D-end (but still amenable to educational stimulus). The acquisition of complex concepts (e.g., photosynthesis or multiple causes of historical events) lies part way along the L-D-spectrum since they develop in complexity in an individual over many years while being strongly under the influence of learning experiences. As far as this chapter is concerned, the development of scientific reasoning is another example of a process which depends on both the development of the central nervous system (the individual's capacity to process complex ideas) and appropriate learning experiences. High-level learning cannot take place without development, and satisfactory cognitive development cannot occur without appropriate cognitive stimulation (learning experiences).

A feature of this Learning-Development-spectrum worth noting is that the *generality* of functions increase as one moves from L to D. At the L-end information learnt tends to be specific and applicable to a narrow range of cognitive functioning. Learning the number of a bus for a particular route is not knowledge that generalises usefully to other contexts. On the other hand, educational experiences which stimulate the development of general intelligence may be expected to have an impact on the effectiveness of all learning, in any intellectual field (and maybe beyond).

The model of a plastic general intelligence proposed here, that is, a general thinking machinery amenable to educational influence, has implications for the whole nature of education. We will return to the question of how science educators can use this model to provide general cognitive stimulation for their students, but now we must consider in more detail some different types of thinking in science which might form the 'subject matter' of a strand in the curriculum devoted to the development of scientific – and by the way, general – thinking.

A System of Thinking Processes That Should Be Developed in Science Education

The processes of thinking have been studied, described and categorised in several psychological and educational research traditions. These approaches often used different theoretical frameworks, terminologies and methods. Among these is the psychometric approach (intelligence research, individual differences approaches, factor analytic studies) which produced a great amount of data of the general cognitive abilities and also contributed significantly to the development of psychological testing and educational assessment (Carroll, 1993).

Piaget and his colleagues emphasised the developmental aspects of cognition, and described the development of thinking through qualitatively different stages. Piaget's work is especially important for science education as his theory explains the origin of reasoning schemes and makes a connection between the manipulation of external objects and the development of higher-order thinking skills. His work has been followed by several Neo-Piagetian researches proposing a number of elaborated models of cognitive development and systems of thinking (e.g., Demetriou, 2004). Piaget's theory and the researches of his followers are especially important for establishing early science education, organising observations and experiments to be carried out by children.

The information processing approach emphasised the differences between novices and experts in the organisation of knowledge. It offers useful models of learning within the content domains, but developmental aspects and reasoning processes are less elaborated in the information processing paradigm. The most recent cognitive neuroscience research studies thinking from another aspect. Its results are not ready for direct application in the field of science education, but the main messages of the results for education are promising: they confirm the claim of the plasticity of the brain and the modifiability of cognitive processes, especially during the early phases of the development (Adey, Csapó, Demetriou, Hautamäki, & Shayer, 2007).

For assessing scientific reasoning we may provide a framework from all these research traditions. However, taking the developmental aspects, the target age groups and the diagnostic orientation into account the Piagetian tradition offers the most useful resources.

There are very many ways in which the cake that we call 'thinking' may be sliced up. In the next section we will first look at a couple of meta-strategies for thinking about thinking, then consider a number of quite general classes of thinking, and then of *dichotomies*. Finally, we will focus on a specific set of 'reasoning patterns' which have particular relevance to science.

Meta-Strategies and General Thinking Processes

Human thinking, in broader practice is never a simple mechanical process. It is always influenced by the actual situation and context as well as the general psychological state of the thinker. Even scientific thinking is often mediated at least at the level of general thinking processes by non-cognitive factors such as motivation, interest and curiosity. Forming science-related attitudes and values may be an important goal of science education, as is the development of beliefs related to the validity of scientific knowledge and the way students think about the status of their own knowledge (personal epistemologies). We will not deal with the affective aspects of learning science in detail in this chapter, but here at the outset we have to mention the possible connection between cognitive and affective processes.

Meta-strategies relate to a person's control over their own thinking process. To some extent they are dispositional but they regulate the whole process of thinking including attention and the choice of deployment of one or another specific types of thinking. There are several research directions which deal with these questions. Meta-cognition is the broadest concept; beyond its importance in scientific reasoning it plays an important role in reading comprehension and mathematical problem solving as well (Csíkos, 2007). These meta-strategies are essential in learning sciences, especially in understanding and mastering complex scientific concepts and ideas.

There are some general thinking processes that are characteristic of some contexts and situations, such as argumentation and critical thinking. It is worth briefly defining them here as well.

Storage and Retrieval

Knowledge about the processes of remembering, also called meta-memory, is more specific than the general processes of self-regulation. These are skills that can be learnt enhancing the thinker's ability to transfer information to and from long-term memory. As human memory stores organised information more efficiently than independent pieces of information, information should be arranged into compact structures before memorising. If the knowledge has a natural structure the best way is to make this structure explicit and the related pieces of information should be memorised by integrating them into this structure. If a unifying structure does not exist, the learner has to create an artificial one and integrate the information into it. For example, a well-known strategy is associating a list of words to be memorised with the parts of a popular building or the houses of a familiar street (method of places). Students with good memorising abilities are able to distinguish between well-structured learning materials when exploring and understanding may result in meaningful conceptual learning, from unstructured information where creating artificial structures may be a better strategy. Storage and retrieval strategies were already studied by Greek philosophers and special techniques (also referred to as *mnemotechnics*) were further developed by the Roman orators.

Self Regulation

This means the ability to attend to the relevant parts of a problem, to analyse personal reasoning and monitor one's own choice of thinking pathways, progress towards a solution and detection of errors and dead-ends. Self regulation includes motivational and other affective aspects as well (Molnár, 2002).

Argumentation (Dialogic)

Dialogic argumentation identifies disagreement among assertions, relates supporting and refuting evidence to each assertion, and weighs all of the evidence "in an integrative evaluation of the relative merit of the opposing views" (Kuhn, 1992, p. 157). Argumentation plays a relevant role in the advancement of science by checking errors and identifying insufficient evidence. Argumentation requires organising statements into a logical order. It is a basic reasoning process in presenting the results of a research, but its potential is not yet fully exploited in science education (Osborne, 2010).

Critical Thinking

Critical thinking belongs to those forms of thinking which are most frequently mentioned both inside and outside the school context. Its improvement is frequently proposed, recently due to the explosion of easily accessible information. One often has to select and classify information and has to evaluate its relevance and validity and has to judge the credibility of its sources. At the same time, definitions of critical thinking are generally difficult to operationalise. The core of critical thinking is usually identified as the ability of collecting, organising and evaluating information.

Most interpretations describe critical thinking as a set of a number of component abilities, and the long lists of components usually include every important form of thinking. The most frequently mentioned attributes of critical thinkers are openness, the intention of checking the reliability of information sources, assessing the foundation and validity of conclusions, evaluating the quality of arguments and the ability of questioning (Norris & Ennis, 1989; Ennis, 1995).

If we look for the distinctiveness of critical thinking, the feature that makes it more than the sum of its components, we find it the way the process of thinking is organised and in its purpose. There is always a strong critical attitude behind a critical thinking act that motivates the thinker to question a given bit of information, statement, model, theory, chain of arguments etc. Thinking processes mobilised by critical attitudes play an essential role in the advancement of science, especially in evaluating results, judging evidence, filtering out sources of errors, and falsifying unjustified statements. Preparing critical analyses and reviews is one of the characteristic activities of the researcher. Science education offers an efficient field for practising critical thinking as the validity of arguments may be judged on the basis of objective criteria.

Dichotomies

Some forms of thinking relevant to science may be characterised by dichotomies, introduced briefly in this section. In few of the following pairs there is not any question of one being 'better' than the other. In all except the case of concrete-abstract, the highest level of thinking involves an integration of both types, or a choice of the most appropriate type for a particular situation.

Quantitative – Qualitative

Quantitative reasoning is characterised by situations where the learner must apply properties and procedures related to number sense and number operations to solve the given problem. Qualitative thinking focuses more on the nature of the variables and judgement for the purpose of comparison or prioritising. In most complex problem-solving situations both quantitative and qualitative reasoning need to be employed.

Concrete – Abstract

Concrete thinking is restricted to actual objects, words, or numbers and simple relationships between them. It allows for simple mathematical manipulation, classification and simple causal relationships. Abstract thinking allows for the imaginary manipulation of factors in a hypothetical model or the possibility of understanding complex relationships such as when there are multiple interacting causes and multiple interacting effects. In this case, there is a clear hierarchy with abstract thinking being far more powerful than concrete thinking. As from abstract constructs further abstract ones can be created, understanding complex systems may require the comprehension of several levels of abstraction. Science offers an excellent context for developing abstraction skills and for demonstrating the concrete-abstract relationship and levels of abstraction.

Convergent – Divergent

Convergent reasoning is used in the type of problem which has one correct answer, so that the reasoning progresses through steps designed to reach this one answer. These steps may include the elimination of extraneous variables, the combination of others, and operations on given data with the aim of reaching the correct solution. Divergent thinking by contrast is discursive, exploring a number of solutions, especially to problems which may have more correct answers. Divergent thinking is also characteristic of creativity, 'thinking outside the box' and 'lateral thinking'. Complex problems may require both divergent and convergent thinking in different phases of their solution.

Wholist – Analyst

The wholist-analytic dichotomy represents a general approach to a problem or to representing and processing information, also identified as cognitive style (Davies & Graff, 2006). Wholist thinking aims for an overview of a situation, to reach a conclusion based on the 'big picture' rather than the detail. The opposite, analytic approach is to focus on the detail and try to solve the problem bit by bit. Analytic thinking is characterised by situations where the learner must apply principles from formal logic in determining necessary and sufficient conditions or in determining if implication of causality occurs among the constraints and conditions provided in the problem stimulus. Excessive wholist thinking may miss important details, and excessive analytic thinking may fail to integrate the parts of a solution into a coherent response. Both types of thinking are useful at appropriate phases of problem-solving. (Note that some authors use 'holist' rather than wholist.)

Deductive – Inductive

The process of deduction is reasoning from the general to the specific or from premises to a logically valid conclusion. Examples are: Conditional (deducing a valid conclusion from a rule of the form "if P, then Q"); Syllogistic (evaluating whether a conclusion necessarily follows from two premises that are assumed to be true) or more generally Propositional reasoning; and Suppositional (Supposing a possibility for the sake of argument, in some cases obtaining a contradiction). Deductive reasoning applies strict logical rules. Consequently, appropriate application of rules to true premises always results in true conclusions. On the other hand, deductive reasoning does not produce originally new knowledge as it expresses in a different form what is there already, although often in a hidden way in the premises. Deductive reasoning is essential in scientific research, errors in a deductive process leading to false conclusions. As Piaget's research demonstrated, children attain a fully developed formal logical system only after a long developmental process (and we may add: if at all), therefore they possess limited tools to comprehend deductive argumentation. (For the development of deductive reasoning and its relevance for science education, see Vidákovich, 1998).

The process of induction is reasoning from particular facts or individual cases to a general conclusion, that is, constructing a general rule or explanatory model from a number of specific instances. Classically, science progresses by a series of inductive and deductive loops, although this rather convergent picture omits the intuitive, creative leap that very often occurs in real scientific advance. From a philosophical point of view, accumulation of positive examples may not prove the truth of a theory in general, therefore, Popper proposed a more sophisticated theory for explaining induction that is based on the concept of falsification (Popper, 1972). Psychological processes of inductive reasoning play significant role in understanding science and application of knowledge in new contexts (Csapó, 1997, 2001a). Its modifiability has been demonstrated in a number of training experiments (Hamers, de Koning, & Sijtsma, 1998; Sanz de Acedo Lizarraga, Sanz de Acedo Baquedano, & Oliver, 2010. Molnár, 2011).

Thinking Patterns, Operations, Abilities

Finally, in this section on taxonomies of thinking we will look at a number of specific reasoning patterns, or 'schemata' which appear to be characteristic of scientific thinking. A variety of terms have been used as comprehensive names for them; for example, patterns, schemes, schemata, operations, skills and abilities. We acknowledge that several terms may be appropriate in different contexts; however, we prefer to use *thinking abilities* as the most general term for them. We note again, that we consider them as plastic abilities, modifiable by systematic educational stimulation.

They vary in the demand they make on intellectual capacity and here they are ordered very approximately in terms of their difficulty. Because these abilities are really aspects of general cognitive development, they are not amenable to direct instruction, but need to be slowly constructed by students in response to maturation and appropriate stimulating experiences.

Piaget and his colleagues studied the development of these reasoning operations by observing children's activities dealing with simple tasks related to scientific phenomena (see Inhelder, & Piaget, 1958; Piaget & Inhelder, 1974, 1976). Other researchers studied them by the means of mental tests. The development of some of these operations was assessed in several projects in Hungary by paper-and-pencil tests (see Csapó, 2003).

Conservation

For an adult it is obvious that a quantity (of matter, number etc.) remains the same if nothing is added or taken away from it. Conservation is the result of development appearing at a certain stage. Before it a child does not recognise that changing insignificant features, e.g., the pouring water from one cup into another one with a different shape does not influence the quantity of the water. Conservation of number (two rows of beads are still the same number when one is stretched) is one of the simplest forms of conservation while recognising that a solid displaces an equal volume of liquid in which it sinks is more demanding.

Seriation

This means not only putting things in order according to one or more properties, but also interpreting a given phenomenon within a series of comparable phenomena in order to assign some plausible meaning to it. E.g., ordering stimuli along a quantitative dimension, such as length (Inhelder & Piaget, 1958; Nagy, 1987). Seriation is a precondition for solving more complicated organising tasks, e.g., trying all setting of an experiment.

Seriation, in general dealing with relations is an essential feature of scientific reasoning. *Transitivity* is a feature of relations frequently necessary to handle. In general, transitivity involves the ability to understand the characteristics of relationships and logically combine two or more relations to draw a conclusion. Combining two or more relations leads to identifying new or more general relations (Glenda, 1996).

Classification

Classification is the ability to classify objects or ideas as belonging to a group and having the characteristics of that group. At its simplest, this may demand no more than grouping objects which have just one variable with two values. ("Group these red and blue squares so that all in each group are the same."). As the number of variables and values increases so does their difficulty, and extra layers of demand are added by empty classes, class inclusion (two classes in which all members of one class are included in the other, as in the proposition "All dogs are animals") and two-way classification. ("Lions are mammals within vertebrates within animals but they are also carnivores.") More complex structures require multiple classification and hierarchical classification (Inhelder & Piaget, 1958; Nagy, 1987).

Combinatorial Reasoning

Combinatorial reasoning is the process of creating complex constructs out of a set of given elements that satisfy the conditions explicitly given or inferred from the situation. This is characterised by situations where the learner must examine a variety of factors, consider all combinations in which they can appear, evaluate each of these individual combinations relative to some objective constraint and then select from or rank the combinations into order. If the conditions and constraints allow a larger number of constructs, all constructs can be created only if a systematic order of enumeration is applied (for a taxonomy of combinatorial operations, see Csapó, 1988; for developmental data see Csapó, 2001b; Nagy, 2004). Creating combinations of conditions or values of variables systematically is often required when designing experiments (Inhelder & Piaget, 1958; Kishta, 1979; Schröder, Bödeker, Edelstein, & Teo, 2000). Physical and chemical experiments offer a great number of possibilities to exercise combinatorial reasoning by exploring all possible settings allowed by the constraints of the equipment and materials. (For the improvement of combinatorial reasoning see also Csapó, 2003.)

Analogical Reasoning

Analogical reasoning can be applied in situations where the learner must solve a problem with a context similar to a problem the learner is familiar with or includes a problem base which the learner has solved in the past. The parameters or the context in the new stimulus material is changed, but the driving factors or causal mechanism is the same or similar. The learner should be able to solve the new problem by interpreting it in the light of past experience with the analogous situation. Where the reality and the analogy are both accessible to direct perception, we refer to this as concrete modelling (for example the notion of temperature rising is modelled by the thread of mercury rising in a thermometer) but where either or both are abstraction, it becomes formal modelling (relating potential difference to water pressure). Analogical reasoning relates two individual objects or phenomena based on their structural similarities. Analogical reasoning is one of the basic mechanisms of transfer and the application of knowledge (Klauer, 1989a). Finding similarities between more than two objects, and analysing the rules of similarities lead to rule induction and inductive reasoning (Polya, 1968). Analogical reasoning helps understanding new scientific phenomena on the basis of already known similar phenomena, as well as application of knowledge in new areas. Therefore, learning science offers several possibilities of improving analogical reasoning (Nagy, 2006).

Proportional Reasoning

Proportional reasoning involves a sense of co-variation and of multiple comparisons, and the ability to mentally store and process several pieces of information. The co-variation is usually assumed to be linear, but in general could be non-linear (e.g., exponential); considering a nonlinear as a linear relationship may lead to oversimplification or a serious thinking error. Proportionality requires the comparison of two or more ratios (Schröder, Bödeker, Edelstein, & Teo, 2000). Proportional reasoning is a basic process involved in several more complex analogical and inductive forms of reasoning (Csapó, 1997). Understanding some basic scientific concepts (e.g., speed) requires proportional reasoning, and one of the obstacles of understanding school science is the lack of a proper level of proportional reasoning (Kishta, 1979). Recent research has also demonstrated that although proportional reasoning develops over a long period (Boyera, Levinea, & Huttenlochera, 2008), it is amenable to training (Jitendra et al., 2009).

Extrapolation

Extrapolation enables learners to use the pattern of data from one area to predict what will happen in another area. Extrapolation is closely related to analogical and inductive reasoning while rules induced from observation in one area are applied to another area not directly explored. In simple cases, extrapolation means extending the scope of relationships beyond the range of measured data or creating new data points. In more general cases extrapolation requires extending complex rules to new, unknown situations. The probability of making errors and invalid extrapolation increases with the distance between the observed and extrapolated data or rules.

Probabilistic Reasoning

Most scientific phenomena as well as events of everyday life depend on probability. There is always a certain probability that it is raining in a given day; that a team wins a given match; or that the exchange rate of a given currency will change. Understanding these phenomena and calculating risks require probabilistic reasoning. Probabilistic inferences are based on past events and assumed (or calculated) likelihoods of future events. Risk analysis depends on this, and the realisation that one or several counter examples do not undermine the validity of an established probabilistic relationship. Development of probabilistic reasoning was studied by Piaget mostly in the context of simple science experiments (Piaget & Inhelder, 1975; Girotto & Gonzalez, 2008).

Correlational Reasoning

Correlational reasoning means dealing with probabilistic relationships when the connection between two features or variables appears only in certain number of cases. Depending on the ratio of the appearances, the strength of the association may be different. Recognising correlational relationships involves observation of cases confirming and not confirming the association, and estimating their ratio (Kuhn, Phelps, & Walters, 1985; Schröder, Bödeker, Edelstein, & Teo, 2000). As it requires observations, collecting and processing contradicting information, mastering correlational reasoning is seldom complete, and its failures may lead to doubtful judgements (Bán, 1998). Research has shown that it develops slowly (Lawson, 1982; Koerber, Sodian, Thoermer, & Nett, 2005), but it can be improved with systematic instruction, especially in science (Lawson, Adi, & Karplus, 1979; Ross & Cousins, 1993).

Separation and Control of Variables

Control of variables is a complex reasoning pattern or strategy which may involve several other simpler reasoning schemes. It is a result of a long developmental process and is reached during the formal reasoning phase. During an early developmental phase, children learn to identify the key components of a system (e.g., the string and the ball in a pendulum), associate variables with them (e.g., length and weight), and differentiate between the values of the variables (e.g., short, long; light, heavy). Investigating the connection between the variables, and determining their dependencies requires systematic manipulation of the variables, changing their values and observing their effects on the others. Control of variables is essential in designing scientific experiments, organising and interpreting results of observations.

Advancing Cognitive Development through Science Education

In the last section we described in some detail a set of thinking abilities which are important in science – but in the first section we intimated that scientific thinking is rooted in general thinking ability, and that the development of one is likely to transfer to the other. Now we must address the question of by what mechanism can students' scientific reasoning (and by extension all of their reasoning) be stimulated? We have made it clear that we do not subscribe to a 'fixed intelligence' viewpoint, but believe in (and have good evidence for) a model of general and specific thinking that is amenable to educational influence. On the Learning-Development spectrum introduced in a previous section, reasoning falls nearer to the Development-end. In other words it is more developmental, and more general than a simple learning task and we should not expect that scientific reasoning (for example the thinking abilities described in the last section) could be taught in a direct instructional manner. Any attempt to 'teach' them as a set of rules to be followed is doomed to failure. The student may memorise the rules but fail to internalise them, to make them his/her own, and it will mean that s/he will be lost when trying to apply the rules. The development of scientific reasoning, as with the development of any reasoning, must necessarily be a slow and organic process in which the students construct the reasoning for themselves.

We now need to say more about what the teacher can do to facilitate this process of construction. We will exemplify the general principles with reference to one particular approach, that of Cognitive Acceleration through Science Education (CASE), and then conclude this section by mentioning briefly how similar principles are employed by a number of other successful programmes for the teaching of thinking. CASE is chosen as the prime exemplar since it has been well-established over a period of 20 years originating from a science context, and has published many examples demonstrating the effectiveness of its approach (Adey, Robertson, & Venville, 2002; Adey & Shayer, 1993, 1994; Shayer, 1999; Shayer & Adey, 2002).

CASE pedagogy is founded in the developmental psychologies of Jean Piaget (1896-1980) and Lev Vygotsky (1896-1934). Whilst they had arguments over some important issues during their lifetime (such as the primacy of language over development or development over language), they agreed about many things, notably:

(1) the impact of the environment on cognitive development;

(2) the at least equal importance of the social as well as the physical environment;

(3) the value to children's development of becoming conscious of their own thinking processes, conscious of themselves as thinkers.

These three principles are the basis of what are called the 'pillars' of cognitive acceleration. Firstly, the specific nature of a stimulating environment is one that is challenging, one that goes beyond what an individual is currently capable of, one that requires intellectual effort to tackle. In Piagetian terms this would be called *Cognitive Conflict*, and for Vygotsky it is working within the *Zone of Proximal Development* – the difference between what a child can do unaided and what they can achieve with the support of a teacher or more able peer. According to Vygotsky, the only good learning is that which is in advance of development (Vygotsky, 1978). The task for the teacher, which is not trivial, is to maintain just the right degree of tension between what her students can manage easily and what they will be incapable of at this stage, no matter what support they receive. This task is made even more difficult when, as is usual, a class contain students of a wide range of cognitive levels. An activity which offers cognitive conflict for one student may seem trivial to another, and impossibly difficult to a third. Activities which are generative of cognitive stimulation for classroom use must have a variety of entry points and an increasing slope of difficulty so that all can make a start, and all encounter some challenge along the way.

Secondly, lessons which promote scientific reasoning provide plenty of opportunities for *social construction*. That is, they encourage students to talk meaningfully to one another, to propose ideas, to justify them, and to challenge others in a reasonable manner. A stimulating classroom is characterised by high-quality dialogue, modelled and orchestrated by the teacher. Those students who are just a few steps ahead of their peers may be especially efficient helping the others as they think in similar way and are sensitive to the obstacles of understanding.

Thirdly, classrooms in which reasoning is being developed are reflective places. Students and the teacher look back on the thinking they have developed and reflect on successes and failures, so that the lessons of the development of a particular reasoning strand can be learnt and transferred to future ‘thinking’ lessons. Metacognition encourages the abstraction of general reasoning principles which can subsequently be applied to new types of reasoning.

In cognitive acceleration these three core ‘pillars’ were originally incorporated into a set of 30 activities aimed at junior secondary students aged 11–14 years (Adey, Shayer, & Yates, 2001) but the principles have now been applied to a younger range of children (Adey, 1998; Adey, Nagy, Robertson, Serret, & Wadsworth, 2003; Adey, Robertson, & Venville, 2001). In all cases, schemata of reasoning such as those described in the last section form the ‘subject matter’ of the activities. For example, starting with the schema of *classification*, in one activity students aged about 7 years are presented in their groups with a collection of seed-like objects including an apple pip, sunflower seeds, a rice grain, small glass beads, lentils, raisins and so on. They are asked to study them and say which are seeds and which are not. Making piles of seeds and not-seeds is easy enough but now they are asked to justify their choices. This leads to much discussion, carefully led in an open-ended manner by the teacher, generating cognitive conflict as the class struggles together towards some set of features by which a seed can be distinguished from a non-seed.

With the youngest children such activities are given about 30 minutes every week, while with the 7 to 9 year olds perhaps activities last an hour and are given once every two weeks over two years. Evaluations (Adey et al., 2002; Shayer & Adey, 2002; Shayer & Adhami, 2011; Venville, Adey, Larkin, & Robertson, 2003) show that such intervention has long term effects on the development of children’s reasoning which transfers to gains in achievement in academic subject areas.

Other programmes which have reported significant effects on children’s reasoning include *Philosophy for Children* (Lipman, Sharp, & Oscanyan, 1980; Topping & Trickey, 2007a, 2007b). Although this training does not have a particular focus on science, the classroom methods applied in this program (interaction between students, discussion, argumentation) may be useful in science education as well. Similarly, science-related philosophical questions may be discussed in this way; furthermore students’ attitudes, beliefs and personal epistemologies may be efficiently formed by this approach. (For the Hungarian adaptation of the *Philosophy for Children* program, see G. Havas, Demeter, & Falus, 1998.)

Another training method for fostering thinking relevant to the education of sciences is Klauer's Inductive Reasoning Program (Klauer, 1989, 1996; Klauer & Phye, 1994, 2008). Originally, the program applied a toolkit designed on the basis of Klauer's model of inductive reasoning (Klauer, 1998b). It proved to be especially effective with young slow-developing students. Later these principles of development were applied both outside the particular school subjects and embedded into them. In a recent experiment, based on Klauer's original model, Molnár (2011) reported successful fostering of inductive reasoning in young children by using playful but well-structured activities. In a current article, Klauer and Phye (2008) reviewed 74 developmental studies which aimed at improving inductive reasoning. Most of the interventions took place in the framework of school subjects, including mathematics, biology, geography, and physics.

Several further experiments demonstrated that science education offers excellent opportunities for fostering thinking abilities. Among others, Csapó (1992, 2003) reported significant improvements in combinatorial reasoning as a result of training embedded in physics and chemistry. Nagy (2006) described an experiment aiming at fostering analogical reasoning in biology that not only improved analogical reasoning but resulted in better understanding and mastery of biology content as well. Beyond the experimental works and intervention studies, this approach – embedding developmental effects into the delivery of science content – may be applied in regular everyday teaching as well. For example, Zátonyi (2001) proposes a number of particular activities for physics education which may serve multiple aims, fostering thinking abilities and a better mastering of the content.

There are several teaching methods which are especially favourable for the advancement of thinking. A recent movement promoting *Inquiry Based Science Education*[1] (IBSE) proposes more observations and experiments in science education. *Problem Based Learning* (PBL) organises teaching materials around realistic issues, often cutting across disciplinary borders, which indicate the relevance of learning specific pieces of information. Dealing with complex problems is not only more chal-

1 IBSE is the model that is supported by European Federation of National Academies of Sciences and Humanities and its Working Group Science Education, see: http://www.allea.org/Pages/ALL/19/243.bGFuZz1FTkc.html. A number of European Commission projects deals with IBSE as well.

lenging but more motivating for young learners as well, compared to the often sterile materials organised by the disciplinary logic. Project work also requires more activities fostering thinking, and helps to integrate knowledge into context. Group projects especially foster communication skills and group problem solving.

Assessing Cognitive Development in Science Education

Assessing reasoning requires tools and methods different from that of assessing how well students learnt content knowledge. The main problem is that assessing thinking always requires content and the familiarity of content may influence the related reasoning and the solution itself. Piaget faced a similar difficulty when he studied children's reasoning processes. Therefore, he applied a method of questioning the students – the *clinical method* – which provided most of the information needed by the examined child so focusing the test on the ability to use and process information. A similar problem has to be solved when assessing thinking: the influence of the content should be minimised.

Content of Assessment

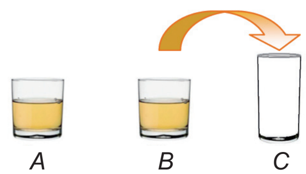
When we are assessing science reasoning, we are by definition not assessing science knowledge, even science conceptual knowledge. The task therefore becomes one of trying to measure a student's ability to reason scientifically while making the least possible demands on their content knowledge. If an item confounds knowledge and reasoning and a student fails, we do not know whether that failure represents a lack of knowledge or inadequate reasoning powers. While it is probably impossible for a reasoning item to demand no knowledge at all (or indeed for a knowledge item to require no reasoning at all), that at least is the ideal to strive for. What knowledge is needed should be provided. For example, if we wish to assess a young child's ability to conserve liquid volume across change of shape we might present an item such as the one on Figure 1.1.

Here are two glasses A and B. They are just the same as each other. Both glasses contain the same amount of apple juice.

Do you agree?

Here is another glass C, taller and thinner than the glass A or B. It is empty.

Now the apple juice from glass B is poured into the tall, thin glass C.



[*This to be done in reality, or on a video / computer*]

Look at the apple juice left in glass A, and the apple juice now in the tall glass C.
Remember, we started with the same amounts in glasses A and B. Then we poured all the juice from B to the thin glass C. Is there now:

More juice in C than A, or
More juice in A than C, or
The same amount of juice in A and C?

What makes you think so?

If you were offered glass A or C to drink, which one would you choose? Why?

Figure 1.1
Testing volume conservation

Below we will consider how items such as this may be administered. Here we will focus further on what sort of reasoning it is that we should be trying to assess. The criteria we will propose within the context of this chapter on science reasoning are that the matter to be assessed should relate to *science*, but should also relate to *general reasoning*. Furthermore it should be appropriate for children aged 6 to 12 years. The categories of reasoning from previous sections of this chapter which fit these criteria are what we described there as the thinking abilities or schemata of concrete operations and some of the schemata of formal operations. Specifically, we would include the following operations:

(1) conservations including number, matter (mass), weight, volume of liquid and displaced volume;
(2) seriation including putting things in order by one variable then re-ordering by a second variable and interpolating new objects into a series;
(3) classification including simple grouping, grouping by two variables, ‘missing’ groups, overlapping classes and hierarchies;
(4) cause and effect including more than one cause of one effect and more than one effect of one cause, the distinction from simple correlation, but not weighting multiple causes or probabilities; including finding simple qualitative relationships between variables;
(5) combinatorial thinking and finding combinations of up to three (or four?) variables each with two or three values;
(6) understanding a basic conception of probability and distinguishing events with lower or higher probability;
(7) basic correlative reasoning, the ability to recognise the correlation based on the proportion of events strengthening and weakening the relationship;
(8) spatial perception including perspective and mental rotation;
(9) speed in terms of distance and time;
(10) control of variables in three variable situations where each variable is directly observable;
(11) ratios of small whole numbers.

Forms of Assessing Reasoning Abilities

As indicated earlier, items assessing scientific reasoning need to be as free as possible from demands for scientific knowledge, and all required knowledge should be provided. The exercise of these aspects of scientific reasoning often requires that each item presents a series of scenarios with the response of the student at each step being observed. This approach is closely related to the principle of dynamic assessment (Tzuriel, 1998) in which what is observed is the subject's ability to learn from experience rather than their crystallised knowledge. There is a similar situation in the assessment of dynamic problem solving (Greiff & Funke, 2010), when students interact with a system presented by a computer, observe the behaviour of the system, generalise the observed rules, and then use this knowledge to solve the given problem. A similar interaction may help to activate students' thinking that then may be recorded by a computer.

For a long time, this type of testing could most reliably be managed by an individual interview and this is the basis of Piaget's clinical method. But such an interview is not a very practical approach for a classroom teacher who wishes to assess her children's current reasoning capability, nor for an education authority interested in school, regional, or national norms. In scaling up a testing method from the one-on-one assessment by a psychologist to a classroom test that can be administered by a non-specialist, some compromises of validity are inevitable. On the other hand, computerised testing can be much closer to the ideal individual interview than a paper-and-pencil assessment. Furthermore, administering the same test to every subject improves the objectivity of the assessment.

One successful example of the development of classroom tasks for assessing levels of cognitive development was the *Science Reasoning Tasks* of Shayer et al. in the 1970s (Shayer, 1970; Shayer, Adey, & Wylam, 1981). Most of the tasks developed were aimed at assessing formal operations (control and exclusion of variables, equilibrium, probability, combinations) but two were targeted at younger students:

(1) *Volume and heaviness* covers simple volume conservation up to density concepts in the Piagetian range from early concrete operations to early formal operations. The administrator demonstrates various actions (pouring liquids, lowering a mass into water in a measuring cylinder, etc.) and takes the class through the items one by one, explaining as necessary. Students answer on a sheet requiring multiple choice or short written answers. This task is suitable for students aged from 8 years upwards.

(2) *Spatial perception* is a drawing task. In one set of items students are required to predict the level of water in a jar as it is tilted (actual jars with water being demonstrated) and in others they are invited to draw a mountain, with a house on the side, then a chimney, then smoke from the chimney, also an avenue of trees going away. This task covers the range from early pre-operational to mature concrete operations and can be used with children as young as 5 years.

Even these assessment tasks are open to errors in administration and they do require some particular pieces of equipment for demonstration. The best promise for the future of assessment of reasoning including science reasoning, is the administration of tasks similar to those described above but using a computer to present the situations, to ask the questions, and even to modify the progress of the test in the light of an individual student's responses by applying the principles of adaptive testing. This approach begins to become possible when all students in a class have access to computers. As handling computers is getting easier and simpler, this promise may be realised soon. We will outline what one such test task might look like on Figure 1.2, taking the schema of classification as an example.

1 The first item screen presents an array of 4 green squares and 4 green triangles of similar size.

The instruction, delivered as text and by audio, is “Can you sort out these shapes? Drag them into two groups so all the shapes in each group are the same”.

2 Array of green squares, triangles, circles.

“Divide these into three groups of similar objects.”

3a A mixture of green and red squares, green and red triangles.

“Make two groups so all the shapes in each group have at least one thing in common. What feature have you used to make your groups? Colour / Shape / Size / other?”

3b “Mix them up again and then divide them into two groups in a different way. What feature have you used this time? Colour / Shape / Size / other?”

3c “Now divide them into four groups. What are the features of the shapes in each group?”

…

Figure 1.2
Classification task

Items can be added of increasing difficulty by increasing the number of variables, the number of values of each variable, by introducing empty sets (e.g., an array of red circles, red squares, blue circles), by introducing hierarchical classification, and by moving to real-life examples (e.g., farm animals). The programme would record the student’s answers, assess competence in classifying at each level, offer more difficult items following success or simpler items following repeated failure, and yield an overall level of performance.

It should be possible to develop tests of this sort for each of the schemata. The question then arises, 'could just one test be developed which tested levels in all or many of the schemata?' One might have, for example, four items relating to classification, another four to conservation, more to do with causality and so on.

There are a number of reasons why such an approach may cause problems. Firstly, within each schema there are many levels of access which cannot be sampled adequately with three or four items. Secondly, in line with the relationship of this type of test with dynamic assessment, it takes a little time for subjects to 'tune in' to the topic of the test. To continually jump from one schema to another is liable to lead to an underestimation of a child's true ability as they have to 're-tune' to each new short set of questions. Finally, although the developmental progress through each schema can be mapped on to and is underpinned by a common scale of cognitive development, and one might expect a child to progress through each of the schemata more or less in synchrony, in fact, variations in experience lead to what Piaget called *decalage* – progress through one schema not keeping precisely in step with others.

For diagnostic purposes it is useful to have a profile of a child's developmental level separately in each of the aspects of science reasoning. This requires a large number of specifically prepared individual tasks. If students are systematically and regularly assessed by computer, and the results of the previous assessments are available before every testing session, the assessment may be customised for the actual developmental level of each student.

Interpretation of Assessments, Results, Strengths and Risks of Schemata Tests

Tests of science reasoning can yield valuable information at various levels. For an individual teacher, to see at first hand the responses of her pupils to a reasoning task can be quite surprising and enlightening and often elicits responses such as "I can't believe they got that 'wrong'" or

“But I only taught them that two weeks ago”. Such reactions may be attributed to the fact that the nature of cognitive development and the relationship of teaching to development are often poorly understood by teachers and the results of reasoning tests can reveal that the development of reasoning such as control of variables or proportional thinking is slower than one might think, and is not amenable to simple direct instruction. Certainly, teachers can help students develop this reasoning but it is a slow process of cognitive stimulation in various contexts rather than a matter of simple instruction alone.

Once they overcome the urge to ‘teach’ the reasoning skills directly, teachers will find the results of reasoning tests useful to inform them of where children are now so that they can (a) map out the long road of cognitive stimulation ahead and (b) better judge what type of activities are likely to cause useful cognitive conflict – both for a class as a whole and for individual children.

On a larger scale, some national (Shayer, Küchemann, & Wylam, 1976; Shayer & Wylam, 1978) and international (Shayer, Demetriou, & Pervez, 1988) norms have been established for the ages of attainment of various levels of development which could allow a teacher, school, or education authority to make some judgement about the performance of their students compared with a wider context. Unfortunately, many of these norms are now quite old and it has been shown that the norms for, for example, the Volume and Heaviness task describe above have changed radically since they were first established in the 1970s (Shayer & Ginsburg, 2009). In spite of this shift, both by internal comparisons within a school and simply by reference to the transparent success criteria that these tests display, it would be possible even from localised testing to identify individual students who may appear to have some science reasoning disability, as well as exceptional students who might benefit from higher-level stimulation than is provided by the regular school curriculum.

The advantage of the type of test that has been discussed in this chapter is that it assesses something more fundamental than science knowledge or understanding. What is assessed has a strong developmental component, is an indicator of general reasoning ability, and underlies all effective learning. By improving the quality of assessment of science reasoning we gain a deeper insight into how our students are thinking scientifically and so are better able to help them through targeted cognitive stimulation to develop their thinking further and so provide them with the tools they need to improve all of their science learning.

But there are some features of science reasoning tests which need attention if their main purpose is not to be thwarted. Firstly, there is a small risk that some people might interpret the score from a reasoning test as a more or less fixed property of the child. Guidance on the use of the tests needs to make clear that even if the reasoning being tested is not easily amenable to direct instruction, it certainly is amenable to longer term, developmentally conscious teaching. It should be emphasised that the purpose of such a testing is to identify the need for intervention and to monitor the effects of the treatment. Science reasoning tests can be used in a formative way as well as can science knowledge tests. Furthermore, it is essential in computerised testing to apply realistic situations. Students should feel the objects and processes presented on the screen as real, otherwise they cannot make a correspondence between the real world and the one presented by the computer.

Secondly, there is the issue of test development through drafting, trialling and item statistics; re-drafting and programming the instruments for computer delivery. As indicated previously we see these tests being best administered one-on-one by individual computers. This is essentially a technical problem.

Finally, there is an issue about security, especially in systems with high-stakes testing. If the developed tests were to become freely available, and if the diagnostic purpose of the tests was misunderstood, they would be prone to coaching. That is, a school or teacher who obtained the tests and thought that there was some merit in being able to report that their students scored highly on the tests (for example in a prospectus to parents) could relatively easily coach students with ‘correct’ answers. This process short-circuits real developmental growth and the artificially inflated scores would not reflect genuine internalisation of the schemata by the students. The best guard against such misuse is education of teachers and school principals, and a policy of discouraging the public reporting of test scores of individuals or groups. The temptation of ‘teaching for testing’ or ‘test coaching’ may be further reduced if testing is regularly repeated, and the data are longitudinally connected. Artificially raising the results at one assessment point would decrease the possibility of having a gain in the consecutive assessments. Furthermore, in the case of longitudinally connected developmental data, manipulation of results may be more easily identified with statistical methods.

This raises also the issue of how such test results should be reported to students themselves. As is normal good formative assessment practice (Black, Harrison, Lee, Marshall, & Wiliam, 2003), feedback should be qualitative rather than quantitative. Simply giving a student a total score on a reasoning task is meaningless since it does not tell him or her sort of thinking at which s/he has been successful, and the sort of thinking that still needs to be developed. An efficient formative feedback, first of all, should advise students to find activities which help them to further develop and to improve the results. The test scores can only help them to control if their work has been efficient, and how it has increased since the last assessment. In a classroom, setting group feedback can actually become a teaching opportunity, as different students are invited to report their choices of answers and to justify them and engage in social construction with others.

Summary

In this chapter we have made a clear distinction between science knowledge and science reasoning, this distinction being partly clarified by their positions on a Learning-Development spectrum, which has implications for their degree of generality. As a consequence of this distinction, we also have to distinguish direct teaching and systematic stimulation of the development. This latter one is the process of improving scientific reasoning as well as fostering thinking in general.

We have seen some ways in which science reasoning may be classified and have paid particular attention to the set of scientific reasoning patterns or schemata which underpin all science learning and understanding. Science reasoning is seen as one aspect of general reasoning, or general intelligence, and both general and science reasoning are open to development through appropriate educational experiences.

We have described the nature of cognitively stimulating experience as typically involving cognitive conflict that challenges students' actual knowledge and motivates them to step further towards a higher level of understanding. We have highlighted the importance of social construction, the processes in which students dispute and argue over science phenomena mutually inspiring each others' reasoning processes. Furthermore, we emphasised the role of metacognition and the significance of becoming a conscious thinker being able to control and monitor our own reasoning processes. We have demonstrated the unique opportunities science education may offer to exercise all these essential cognitive processes.

Finally, methods of assessing students' powers of reasoning in science have been introduced. We also have provided some pointers and criteria from which it might be possible to start to develop banks of appropriate test items. The uses and potential misuses of such tests have been considered.

Formative and diagnostic assessment of scientific reasoning has already been explored in experimental educational programs for several decades. However, the demands of human and instrumental resources required for the assessment of students' reasoning prevented these methods from being broadly applied in everyday educational practice. Technology-based assessment makes personalised testing accessible in average classrooms and in this way helps to take a further step towards adjusting science education to the actual developmental level and individual needs of students.

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2

Science Literacy and the Application of Scientific Knowledge

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Introduction

In formulating the objectives and goals of science education, considerations of social needs have received increasingly more attention over the past few decades. Within the socially relevant body of knowledge, a key role is assigned to skills and competencies that provide an awareness of natural sciences, enable students to apply their knowledge in everyday life, equip them for independent learning, for the acquisition of information and for decision-making, and help them become responsible members of their society. A major line of research in natural science education is concerned with social issues of education, the nature of relevant knowledge, the interpretation of science literacy, the comprehensive analysis of the various models (e.g., Aikenhead, 2007; Bybee, 1997b; Jenkins, 1994; Laugksch, 2000; Pella, O'Hearn & Gale, 1966; Roberts, 2007) and the planning, analysis and evaluation of educational programs and teaching and learning environments focusing on scientific literacy.

The greatest challenge of science education is to keep up with the development of science and technology and with the changes in the modern social and economic environment. It has become clear by now that a discipline-centred approach to education mirroring the structure and logic of specialised branches of science is in itself incapable of the efficient teaching of the ever newer results of science while satisfying the changing needs of society. Empirical research has shown that the successful application of the scientific knowledge acquired through traditional teaching methods at school is largely limited to the original environment of acquisition, therefore, it is difficult to transfer this knowledge to contexts outside of the school (Csapó, 1999). The results of research on the organisation, acquisition and use of knowledge indicate that the development of reasoning and efficient learning skills plays a major role in the development of applicable knowledge. The data gathered during the past decades show that the ability to apply knowledge to new situations and in a variety of contexts is improved by teaching methods encouraging active knowledge acquisition and independent learning. Efficient education also takes the social embeddedness of science, the scenes and modes of knowledge acquisition outside of school into account, and attempts to narrow the gap between formal and natural learning. While the idea that education should meet socio-economic needs receives the greatest emphasis in the theoretical framework of the Organisation for Economic Co-operation and Development, Program for International Student Assessment (OECD PISA) programs several countries have also made efforts to develop literacy standards conforming to national characteristics and cultural traditions, to establish practices encouraging science education, and to measure scientific knowledge on a regular basis. The first part of this chapter discusses the diverse approaches to scientific literacy, outlines the models representing the principal trends in national standards and international studies, and presents some specific concepts of literacy. The second half of the chapter reviews the structure of scientific literacy and of the knowledge expected to be acquired and intended to be measured, discusses the curricular and assessment requirements, and analyses the issues of knowledge application.

Different Approaches to Science Literacy

The present-day interpretation of the objectives of science education can be traced back to Conant (1952), a Professor of Chemistry, a former president of Harvard University. In the early fifties, he was the first to note that the knowledge of the facts of science and technology is relatively low-level knowledge in itself, and he emphasized the importance of the comprehensive understanding of science (Bybee, 1997b). The term *scientific literacy* encompassing the basic principles and objectives of science education was coined by Hurd (1958) and McCurdy (1958). *Scientific literacy* as a concept standing for the goals of 'school science' became a common term in the Anglo-American literature debating curriculum developments in the second half of the 20th century. The modern interpretation of the concept relating scientific knowledge to practice and to fields other than science did not, however, emerges until much later (Roberts, 2007). In the 1980s, the term *scientific literacy* was replaced by the phrase *science literacy* in the projects of the *Science-Technology-Society* (STS) and then in the theoretical framework of the PISA program of the OECD (Roberts, 2007). Although the two phrases (*scientific/science literacy*)[1] are translated with the same expression in the Hungarian literature, there is a difference between them in terms of both content and emphasis. The term *science literacy* is usually used by authors in a wider sense. Within the theoretical framework of *Project 2061* (American Association for the Advancement of Science [AAAS]) it refers to the basic principles of literacy closely related to the natural sciences (AAAS, 1983; 1989; 1990; Roberts, 2007). According to Maienschein's (1998) analysis, the phrase *science literacy* can be associated with approaches focusing on the acquisition of science and technology-related knowledge, whereas the phrase *scientific literacy* is used primarily in definitions emphasising a scientific approach to knowledge acquisition and creative thinking about the physical world.

Today several conceptions of literacy exist side by side differing in detail and complexity (Jenkins, 1994; Roberts, 1983). A number of researchers have attempted to review and systematise the many kinds of

1 A form used more rarely, but with the same meaning and function is *scientific culture* (please refer e.g., to Solomon, 1998), and in French-speaking regions (e.g., Canada) '*la culture scientifique*' (Durant, 1993).

interpretations. These studies categorise the various approaches to literacy according to different guiding principles and criteria. Laugksch (2000) observes, for instance, that the interests and objectives of teachers and other professionals involved in science education are a decisive factor in their definition of concepts and tasks and in their placement of emphasis. Primary and secondary school teachers thus aim to specify in the curriculum the skills, attitudes and values related to their objectives, and to interconnect educationally relevant scientific results, teaching methods and assessment. Sociologists and other researchers in social sciences with an interest in natural sciences, who mainly work with adults, emphasise the power of science and technology, and the importance of scientific knowledge needed in everyday life. Those involved in natural science education outside of school (e.g., educators working in botanical gardens, zoological gardens or museums), writers and journalists focus on the development of the literacy of a wide range of age groups (children, teenagers, adults, the elderly), on comprehensibility and on the dissemination of applicable knowledge.

In his overview of the different definitions of scientific literacy, Roberts (2007) identifies the following approaches: (1) a historical approach, which is common among qualified teachers, (2) an approach built on the assumed needs of students, focusing on types and levels of literacy, (3) an approach concentrating on the word literacy, (4) an approach focusing on the natural sciences and natural scientists, (5) and an approach centred on situations or contexts of everyday life related to science. The author assigns literacy conceptions to two categories clearly distinguishable in terms of their view of the fields of natural science and the relationship between them. One of these is 'Vision I, rooted in the products and processes of science,' which is associated with the traditional school teaching of science, – see e.g., Shamos's (1995) model. The models adopting 'Vision II' emphasise the understanding of situations and contexts which are likely to occur in the everyday lives of target groups and which contain science components or are in some way related to the principles and laws of science – one example is the conceptual and procedural literacy level described by Bybee (1997a). Roberts (2007) points out that for 'Vision I' a situation is just a symbolic component of literacy, while in 'Vision II' the different disciplines of science do not receive sufficient emphasis.

Aikenhead (2007) proposes a third category to supplement 'Visions I and II,' which are both based on the conventional notion of science and on its disciplinary versus interdisciplinary conception. Aikenhead terms the complex, plural definitions of the third category combining natural sciences with other disciplines (with social sciences, such as sociology) 'Vision III' after *Roberts*. One example is the view on literacy embraced by the STS projects (Aikenhead, 1994; 2000; 2003b; B. Németh, 2008; Fensham, 1985; 1988; 1992). The conceptions of literacy used in practice are individual manifestations and various combinations of Roberts' 'Visions'(Aikenhead, 2007; Roberts, 2007).

Holbrook and Rannikmae (2009) distinguish two opposing poles of literacy models: those focusing on the *knowledge of science* and those emphasising the usefulness of *science literacy*, between which Gräber's (2000) model creates a bridge.

The models varying in their approaches and in their formulations – as discussed in the comprehensive analytical studies cited above (Aikenhead, 2007; Gräber, 2000; Holbrook & Rannikmae, 2009; Laugksch, 2000; Roberts, 2007) – characterise scientific literacy from differing perspectives and along varying dimensions. A feature common to these approaches is, however, that almost all of them describe the competencies a scientifically literate individual possesses, what this individual knows and is able to do. Some literacy concepts list the components regarded to be important, and specify the various forms of literacy corresponding to these components (*descriptive literacy models*). Other approaches distinguish different, hierarchically organised levels emerging with the development of reasoning (*developmental models*). A third group comprises theories characterising scientific literacy through the concept of competency and competency models (*competency based definitions*). In what follows, the diversity of approaches to literacy will be illustrated through a discussion of a widely cited representative of each of the three categories, including the literacy interpretations of the two most significant international assessment studies, the IEA TIMSS[2] and the OECD PISA programs.

2 IEA: International Association for the Evaluation of Education Achievement
The TIMSS acronym in itself refers to the four joint projects in mathematical and natural science organised between 1995 and 2007 (www.timss.bc.edu). Reports: in 1995 TIMSS (Third International Mathematics and Science Study); in 1999 TIMSS-R (Third International Mathematics and Science Study Repeat); in 2003 TIMSS (Trend International Mathematics and Science Study); in 2007 TIMSS (Trends in International Mathematics and Science Study).

Descriptive Approaches to Literacy

Forty years after the appearance of the term *scientific literacy*, *Hurd* (1998) interprets the concept in terms of the role it plays in culture. He lists seven patterns of behaviour required for the interpretation of the relationship between nature and technology. According to that, an individual competent in natural sciences …

(1) understands the nature of knowledge;
(2) applies appropriate science concepts, principles, laws and theories in interacting with his universe;
(3) uses the processes of science in problem solving, making decisions, and furthering his own understanding of the universe;
(4) interacts with the values that underline science;
(5) understands and appreciates the joint enterprise of science, and the interrelationship of these with each other and with other aspects of society;
(6) extends science education throughout his or her life;
(7) develops numerous manipulative skills associated with science and technology.

An approach to literacy similar to Hurd's is reflected in Klopfer's (1991) model, which contends that scientific literacy providing important general knowledge for everyone includes the knowledge of essential scientific facts, concepts, principles and theories, the application of this knowledge in everyday situations, the ability to learn and use scientific research processes, a thorough understanding of the nature of interactions between science, technology and society, and a scientific curiosity and attitude.

Hackling and Prain's (2008) model, which provides the theoretical background for the Australian *National Assessment Program - Science Literacy (NAP-SL),* constructs a picture of scientific literacy from elements reminiscent of Klopfer's model. Hackling and Prain (2008, p. 7) see scientific literacy as knowledge constructed from knowledge of the nature of science, from a thorough conceptual understanding allowing applications in everyday life, from scientific competencies, and from a positive attitude towards and interest in science.

Shen (1975) defines science literacy as knowledge related to the natural, medical and engineering sciences coming from different sources, including learning in the school and outside of school. The author identifies three types of science literacy based on the organisation of dominant components: (1) practical science literacy, through which the problems of everyday life can be solved, (2) civic science literacy, which ensures social integration through an understanding of science and issues connected with it, and (3) cultural science literacy, which involves scientific curiosity.

The Scientific Literacy Framework of the IEA-TIMSS Surveys

The IEA TIMSS international comparative surveys, which have some of the greatest impact on education system development, are designed to gather data for education policy and school subject development, and to monitor the attainment of curricular goals and evaluate the quality of the attained curriculum (Olsen, 2004). The theoretical basis of the 'descriptive rationale-based' TIMSS projects (Olsen, Lie, & Turmo, 2001) is provided by the so-called international curriculum panel created through an analysis of participating countries' intended curricula indirectly reflecting social expectations (Mullis et al., 2005). The nature of the knowledge/literacy measured by the TIMSS surveys is described in published background materials detailing the theoretical framework of the surveys. The surveys focus on knowledge associated with traditionally defined fields of science. The theoretical framework of the TIMSS projects embraces an approach involving expert knowledge, i.e., it gives rise to models based partly on true scientific literacy of the type described by Shamos (1995), and partly on learnt knowledge in Laugksch's (2000) sense and on the concepts identified by Roberts (2007) as 'Vision I'. The two most recent – 2003 and 2007 – cycles of the TIMSS surveys also included some elements of Bybee's (1997a) procedural view and of Roberts' 'Vision II'.

In the surveys of the IEA, science literacy is defined explicitly only in the theoretical framework of the IEA TIMSS study of 1995 designed to assess the performance of final year secondary school students (Population III). In that work, science literacy is defined as knowledge of science sufficient for the solving of everyday problems. The document identifies three components of knowledge useful in everyday situations: (1) familiarity with the basic principles of the various disciplines,[3] (2) reasoning in mathematical, natural and engineering sciences, and (3) familiarity with the social effects of science and technology, and with the social utility of mathematics, science and technology (Orpwood & Garden, 1998, pp. 10–11). However, the latter two components – Reasoning and Social Utility (RSU) – had limited contribution to the study as they were represented by only 12 items (15.8 per cent of the total number of items) (Adams & Gonzalez, 1996), and these items were completed by secondary school students in only a few countries (Orpwood, 2001).

Development Models

The Shamos[4] (1995) and Bybee[5] (1997a) models regarded as corner points in the relevant literature (Aikenhead, 2007; Gräber, 2000; Holbrook & Rannikmae, 2009; Laugksch, 2000; Roberts, 2007) view scientific literacy as a knowledge structure emerging in harmony with the evolution of reasoning. In both models, the organisation of knowledge is realised in steps building upon one another. Each individual level is characterised by a system of given complexity allowing the completion of tasks of a corresponding degree of difficulty (Bybee, 1997a; Shamos, 1995).

According to Shamos (1995), the most developed and highest-level true scientific literacy essentially consists of knowledge of the major conceptual schemes and the recognition of values and the importance of analytic and deductive reasoning and the significance of scientific problems (Figure 2.1). The emergence of such broad scientific knowledge is contingent on the availability of background knowledge including the elements of scientific communication, cultural scientific literacy as well as functional scientific literacy built upon it, which allows the use of scientific language and fluent oral and written discourses in different situations. Regarding the teaching of science, Shamos (1995) emphasises the importance of logical reasoning, quantitative analysis, meaningful questioning and reliance upon sound evidence as opposed to imparting knowledge content (Shamos, 1995).

3 Earth Science, Human Biology, Other Life Sciences, Energy and Other Physical Sciences
4 Shamos (1995) model: 'Vision I' (Roberts, 2007); meta-competence (Gräber, 2000
5 Bybee (1997a) model: 'Vision II' (Roberts, 2007); material competence (Gräber, 2000)

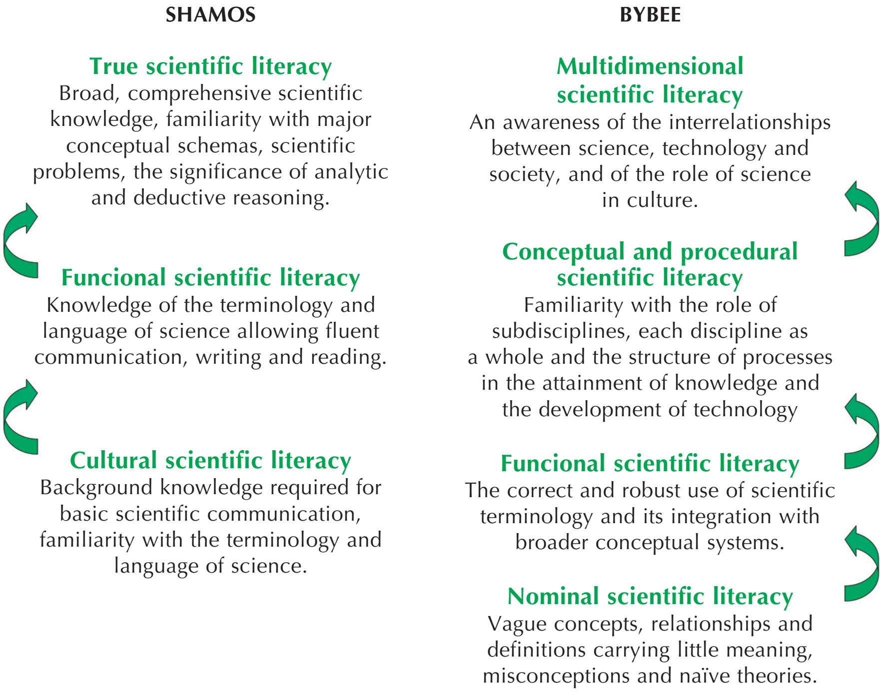


Figure 2.1
Shamos (1995) and Bybee's (1997a) hierarchical models of development

Bybee (1997a) links technical and scientific literacy to the development of conceptual reasoning, and describes literacy as a hierarchically constructed system resulting in an increasingly thorough understanding of the phenomena of science and technology and the interactions between them. According to the model (Figure 2.1), the knowledge of a student is first characterised by concepts and relationships having little meaning, misconceptions and naive theories. This is termed *nominal scientific literacy*, which, with the development of broader conceptual systems, grows into *functional scientific literacy*, i.e., a set of scientific tools that can be used robustly in certain limited contexts. The third level of development, *procedural scientific literacy* enables the learner to understand the structure of the individual fields and processes of science and recognise its role in knowledge acquisition and in the development of technology. Finally, the main conceptual systems of science will be arranged in multidimensional structures giving rise to *multidimensional scientific literacy*, with the help of which the different fields of science, the relationships between science, technology and society, as well as the role played by science in culture and society becomes interpretable. According to Bybee (1997a), this highest organisational level is primarily required by people working in areas related to science (B. Németh, 2008; Bybee, 1997a).

An intention to develop a broad scientific literacy – similar to Bybee's procedural literacy concept – needed for success in everyday life can be observed in the US National Science Education Standards (NSES) published in 1996 in the United States. According to the definition of the National Research Council (NRC), scientific literacy useful for everyone consists of the knowledge and understanding of scientific concepts and processes that help in making individual decisions (NRC, 1996). Scientific literacy empowers people to understand articles published in the popular press (not science journals) discussing science topics and reporting scientific achievements, and to participate in public discourses concerning the validity of the conclusions drawn. Scientific literacy encompasses the comprehension of scientific statements justifying national and local decisions as well as the ability to take a stance based on scientific and technical information. An individual educated in science is capable of describing and explaining natural phenomena, of judging the value of scientific information on the basis of its source and the way it was produced, and of organising, evaluating and applying evidence-based arguments (B. Németh, 2010; NRC, 1996, p. 22).

The revised assessment framework published in 2005 specifies familiarity with the history of science, the scientific forms of thinking, the social and individual perspectives of science, and the characteristics of scientific initiatives as parts of scientific literacy. It highlights three elements for the purposes of assessment: (1) scientific knowledge, (2) scientific reasoning, and (3) the understanding and application of the nature of scientific discovery (Wilson & Bertenthal, 2005, pp. 38–39).

"The goals for school science in the NSES are to educate students that are able to

(i) use scientific principles and processes appropriately in making personal decisions

(ii) experience the richness and excitement of knowing about and understanding the natural word
(iii) increase their economic productivity, and
(iv) engage intelligently in public discourse and debate about matters of scientific and technological concern." (Lederman & Lederman 2007, p. 350)

The influence of the Bybee model can be detected in the Scientific and Technological Literacy (STL) project concerning classroom activities of the OECD PISA program and of UNESCO. UNESCO distinguishes

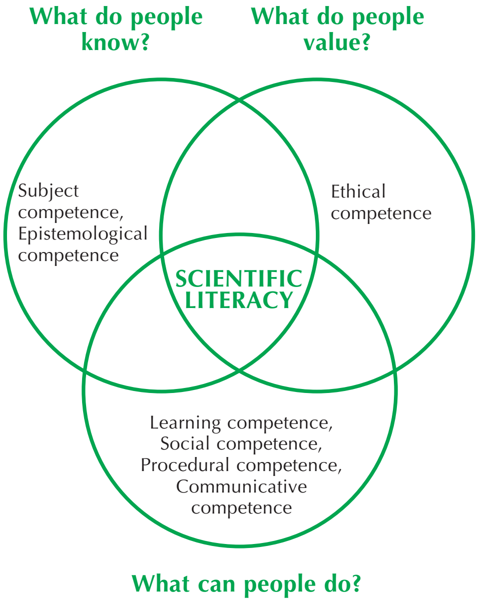
"(1) *Nominal STL literacy*: students identify terms and concepts as being scientific in nature, but they have misconceptions and only provide naive explanations of scientific concepts.
(2) F*unctional STL literacy*: students can describe a concept but with a limited understanding of it.
(3) *Structural STL literacy*: students are interested in the study of a scientific concept and construct appropriate meaning of the concept from experiences.
(4) *Multi-dimensional STL literacy*: Students understand the place of science among other disciplines, know the history and nature of science, and understand the interactions between science and society. The multi-dimensional level of literacy cultivates and reinforces life-long learning in which individuals develop and retain the need to know, and have acquired the skills to ask and answer appropriate questions." (UNESCO, 2001, p. 21)

Competence-Based Approaches

The third large group of approaches to literacy emphasises the complexity of scientific literacy, and the complex nature of knowledge required for problem-solving. It uses competency models[6] to characterise basic expectations. One of the most-cited competence-based approaches is Gräber's model (2000), with an underlying assumption that scientific

6 At this point a terminological clarification is required regarding the usage of competence and competency. Examining the usage of these two concepts in the cited literature suggests that there is a slight difference between the connotations associated with each term. Therefore, the authors use these words in accordance with how they occur in the primary sources. In other contexts, in the plural, only the term competencies is used in this chapter.

literacy that prepares people for the challenges of our complex world is composed of problem solving competencies. In the model, scientific literacy is the cross-section of the competencies related to three problem areas – 'What do people know?' 'What do people value?', and 'What can people do?' – a complex system of subject-related, epistemological, ethical, learning, social, procedural and communication competencies (Figure 2.2).



– *Subject-competence.* includes declarative and conceptual knowledge: a continuum of science knowledge and understanding throughout the various domains of science. When combined, depth and breadth provide an individual profile of science knowledge and understanding.
– *Epistemological competence* includes insight into (the general idea of) the systematic approach of science as one way of seeing the world, as compared with technology, the fine arts, religion, etc.
– *Ethical competence* includes knowledge of norms, an understanding of the relativity of norms in time and location, and the ability to reflect norms and develop value hierarchies.
– *Learning competence* includes the ability to use different learning strategies and ways of constructing scientific knowledge.
– *Social competence* includes the ability to co-operate in teams in order to collect, produce, process or interpret. in short, to make use of scientific information.
– *Procedural competence* includes abilities to observe, to experiment, to evaluate; an ability to make and interpret graphic representations, to use statistical and mathematical skills, to investigate literature. It also includes the ability to use thought models, to analyze critically, to generate and test hypotheses.
– *Communicative competence* includes competence in using and understanding scientific language, reporting, reading and arguing scientific information.

Figure 2.2
The model of scientific literacy (Gräber, 2000, p. 106)

The concept of competency is used not only for individual literacy models, but also for systematising different approaches, and for describing the different developmental levels of literacy. In the analysis of Gräber (2000), the definitions of scientific literacy form a continuum between subject-competence at one end and meta-competence at the other; one of the terminal points is represented with the model of Shamos (1995) focusing on methods and procedures, and the other end is occupied by the theory of Bybee (1997a) emphasising everyday situations and cross-curriculum competences.

Klieme et al. (2003) use the competence theory of Weinert (2001)[7] to define scientific competencies and classify literacy approaches. Pairing the goals of education with real, specific problems, the authors identify four different categories: normative, structural, developmental and empirical literacy models. In terms of this classification, the theoretical framework of IEA-TIMSS is an empirical model, and the procedural approach of Bybee (1997a) is a normative model (Schecker & Parchmann, 2006, p. 49 and p. 52). Using a normative model representing the principles of science education and its traditional fields, the German National Educational Standards (Nationale Bildungsstardards [NBS]) define curriculum requirements with respect to the three disciplines (biology, physics and chemistry) to be met on completion of lower secondary school (Grade 10) (Schecker & Parchmann, 2007).

The curriculum standards of Taiwan also rely on the concept of competence in their specification of the set of requirements expected from students of different ages. The Taiwan curriculum standards use competence indicators to characterise students' level of knowledge/literacy attained by the end of grades 2, 4, 6 9: (1) process skills, (2) cognition of science and technology, (3) nature of science, (4) development of technology, (5) scientific attitudes, (6) habits of thinking, (7) applications of science, (8) design and production (B. Németh, 2010; Chiu, 2007).

The OECD PISA Definition of Science Literacy

One of the best-known and most effective competence-based literacy models was developed by the OECD PISA program. In contrast with the IEA TIMSS studies, the starting point of PISA approach is not the educational material specified by the curriculum and taught at schools but a concept of scientific literacy needed for success in everyday life as defined by a Functional Expert Group. Their interpretation of the concept is a special combination of Roberts' 'Visions I, II, and III' (Tiberghein,

7 *Weinert* is the founder of the conceptual system of OECD-PISA, and one of the developers of key competencies within the OECD-DeSeCo project (Weinert, 1999; 2001).

2007), with certain elements being similar to the procedural literacy level of Bybee (1997a). The model describes essential knowledge and competencies that meet economic and social expectations and are necessary for entering the labour market (Olsen, Lie, & Turmo, 2001). According to this definition, scientific literacy is "…the capacity to use scientific knowledge, to identify questions (investigate), and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity". (OECD, 1999, p. 60)

In the 2006 cycle of the OECD PISA literacy assessment, where scientific literacy was in special focus, a questionnaire aiming at measuring students' scientific and technological attitudes was also included. It was designed to assess an interest in science, support for scientific enquiry, and motivation to act responsibly towards nature and research on the natural environment (B. Németh, 2008; B. Németh, Korom, & Nagy, 2012; OECD, 2006, pp. 35–36).

According to the definition of the Science Expert Group, scientific literacy involves the followings …

"– Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, to draw evidence-based conclusions about science-related issues.
– Understanding of the characteristic features of science as a form of human knowledge and enquiry.
– Awareness of how science and technology shape our material, intellectual, and cultural environments.
– Willingness to engage in science-related issues, and with the ideas of science as a reflective citizen". (OECD, 2006, p. 23)

Comprehensive literature reviews on the approaches to literacy have shown that the definitions of scientific literacy in the official documents of education systems and in the theoretical frameworks of assessment programmes vary greatly in terms of the relationships between the different fields of natural science and the relationships between natural science and other domains (such as social sciences) (Aikenhead, 2007; Roberts, 2007). Documents (theoretical frameworks and standards) created for specific educational, pedagogical or evaluation purposes rely on literacy models either explicitly (as in the Australian and German standards) or implicitly (as in the US standards, the theoretical framework for IEA surveys). Theoretical studies define literacy in terms of the characteristics of individuals competent in science, through the specification of the range of expected patterns of behaviour and the parameters defining these patterns (along content, cognitive and contextual dimensions), and through affective characteristics (e.g., emotional attitude).

Assessment of Science Literacy

One element shared by the slightly confusing variety of views on scientific literacy is that scientific literacy is defined as operational knowledge deployable in a range of situations that enables an individual to solve real-world problems. The successful completion of tasks presupposes an ability to decide what to do in any given situation and an ability to perform the required action. It is well known that problem-solving is facilitated by the familiarity of an environment (situation). This is because during the learning process the circumstances of the problem are registered together with the solution and the result that the recall of the knowledge required for problem solving is affected by the degree of similarity between the learning and the target situations (Tulving, 1979; Wisemann & Tulving, 1976). The knowledge/literacy to be taught and/or measured is therefore characterised by the knowledge and skills, abilities or competencies required for the desired action and by the circumstances of the situation or action, the details of its content, cognitive aspect and context.

One of the fundamental challenges facing institutional education is to be able to teach knowledge that can be applied to new problems and in situations differing from the one in which learning took place. Scientific and technical knowledge can be characterised by the answers given to questions such as 'What?', 'How?' and 'Where, under what circumstances to know?' (Bybee, 1997a). The operationalisation of educational goals and student performance are usually realised by recording the object of learning and knowledge (content, information/What to know?) and the cognitive mechanisms (How to know?) (e.g., in the IEA TIMSS surveys). There are relatively few three-dimensional taxonomies incorporating transfer or context (one example is the OECD PISA program/OECD, 2000; 2006).

The Assessment of Content

Two solutions are known in the literature to the problem of characterising the object (content) of an activity. In theoretical studies supporting the operationalisation of the knowledge that is to be assessed the various categories are defined in terms of types of knowledge. Zoltán Báthory (2000), for instance, distinguishes facts, concepts and correlations, while Anderson and Krathwohl (2001) and Anderson (2005, p. 10) distinguish facts, concepts and the elements of procedural and meta-cognitive knowledge.

The curriculum and assessment standards and evaluation frameworks embracing a wide range of contents categorise knowledge according to general criteria as dictated by a given definition of literacy, and in terms of the disciplines of science and their integrated thematic units. The resulting broad categories are then broken down to different levels of subtopics detailing specific knowledge content. For example, in the handbook on evaluation edited by Bloom et al. and published in 1971, Kloppfer uses content categories such as *The structure and functions of the cell*, *Chemical changes*, *Electrochemistry*, *Sound*, *Dynamics*, *Solar system*, *Oceanography*, and *The characteristics and structure of sciences* (Kloppfer, 1971, pp. 561–641).

In the United States, the organising principles of the US National Science Education Standards (NSES) are centred around the topics of *History and nature of science*, *Personal and social perspectives of science and technology, Life and physical sciences*, and *Earth and space* (Ellis, 2003, p. 39). The NSES identifies eight different categories of content – Inquiry, Physical Science, Biological Science, Earth and Space, Unifying Concepts and Processes, Science and Technology, Science in Social and Personal Perspectives and History and Nature of Science (NRC, 1996).

In the Australian National Assessment Program, scientific literacy covers four content areas based on national and regional curricula: (1) *Earth and beyond*, (2) *Energy and change*, (3) *Life and living*, and (4) *Natural and processed materials* (MCEETYA, 2006, p. 83).

In Taiwan, the system of knowledge content to be assessed covers five areas: (1) *Composition and properties of nature*, (2) *Effect of nature*, (3) *Evolution and continuity*, (4) *Life and environment*, and (5) *Sustainable development*. The subdivision of the five top-level categories creates a comprehensive and clearly organised system. For example, the sub-section *Change and equilibrium* within the main subject of *Effect of nature* contains topics such as Movement and force, Chemical reactions and Chemical equilibrium (Chiu, 2007, p. 311).

The German Educational Standards (NBS) specify the educational goals related to the three traditional science disciplines and detail the content dimension under the heading of 'basic concepts'. The basic concepts are the classic questions of the fields of biology, physics and chemistry. The knowledge prescribed by the physics standards, for instance, relates to the topics of matter, energy, interaction and system (Schecker & Parchmann, 2007).

The content dimension of the science surveys of the IEA also relies on a division into separate science disciplines. The thematic units of every data collection conducted so far have covered Biology/Life science, Earth science and the two physical sciences, Chemistry and Physics. The categories representing the traditional fields of science were supplemented by the category *Environmental issues and the nature of science* in the 1995 cycle of TIMSS, by the categories of *Environmental and resource issues* and *Scientific inquiry and the nature of science* in the 1999 assessment, and by the topic of *Environmental sciences* in 2003. There has been little change in the list of the main and sub-units of the content dimension or in their relative proportions. Although the two most recent studies placed approximately equal emphasis on the various fields of science, an overall bias can be observed in favour of Biology (or life science) and Physics (B. Németh, 2008; Beaton et al., 1996; Keeves, 1992a, p. 64; Martin et al., 2000; Mullis et al., 2001, pp. 37–70; 2005, pp. 41–77; 2009, p. 50).

The OECD PISA programs strive to select knowledge content test items that are relevant, useful in real-life situations, represent foundational scientific knowledge and are important in the labour market (OECD, 1999, p. 63; 2006, pp. 32–33). Although in the OECD PISA surveys, neither the content prescribed by the curricula, nor the content that has been taught at schools is relevant for item selection, some of the test contents are covered by the subject areas of science education in participating countries (Olsen, Lie, & Turmo, 2001).

The *Knowledge* domain of the first two PISA surveys (conducted in 2000 and in 2003) covers thirteen topics related to science disciplines and includes integrative concepts and knowledge components that are important for everyday life and needed for interpreting and explaining certain features of our environment. For example: *Chemical and physical changes*, *Forces and movement*, *Human biology*, *Atmospheric changes* etc. (B. Németh, 2008; OECD, 1999, p. 64; 2003, p. 136).

In the PISA assessment of 2006, where scientific literacy was in focus, the assessed content was based on a knowledge system related to science and nature and necessary for the understanding of nature. The ratio of the two major areas of the *Knowledge* dimension in the tests, i.e. knowledge of science and knowledge about science, was 3 to 2 (OECD PISA, 2006). The category of the knowledge of science is made up of the thematic units of the four major fields of science (Physical systems, Living systems, Earth and space systems, Technology systems). For example, the category of *Living systems* covers the topics of *Cells, Humans, Populations, Ecosystems and Biosphere*. The category of knowledge about science tests two concepts: scientific explanations and scientific enquiry. The latter is, for instance, divided into topics such as *Measurement*, *Data type*, *Characteristics of results*, etc.

The Assessment of Cognitive Dimension

Scientific literacy is defined by every literacy model – regardless of its approach, emphasis and formulation – as applicable knowledge. The notion of application is used widely and with a variety of interpretations. Sternberg (1985), for instance, lists application as the fourth step of the seven steps of creative reasoning, and interprets it as a process of rule generation through the extrapolation of old and new concepts. Passey (1999) juxtaposes application with abstraction and transfer.

In educational sciences, the concept of application is generally used as a synonym for operationalising and putting knowledge to use as a tool. The different interpretations usually link it to various activities related to task completion (counting, interpretation, depiction, linking, modification, supplementation, verification etc.; e.g., Anderson & Krathwohl, 2001; Mullis et al., 2005, pp. 41–77; Nagy, 1979). Huitt (2004) defines application as the use of data and principles in solving problems or tasks, and as selection and transfer. According to another approach, application is the selection and use of information (rules, methods and theories) in new and concrete contexts in an effort to complete tasks and solve problems.[8] According to the interpretation of József Nagy (1979), application is an operative (transforming) and cognitive activity.

In education theory, knowledge is considered to be applicable if it can be successfully used to deal with given real-world problems. In this framework, scientific literacy as applicable knowledge is characterised by answers to questions such as "How to know?", "What to be able to do?". The desired behaviour is organised into a hierarchical system based on various cognitive taxonomies. Application is considered to be an autonomous category in several taxonomies, marked by the labels "*apply*", "*applying*", or "*application*" (e.g., the First International Science Study of IEA – Commbers and Keevs, 1973; Mullis et al., 2009, p. 50; also Anderson & Krathwohl, 2001; Bloom, 1956; Madaus et al., 1973). In curriculum and assessment standards, cognitive activity is usually characterised by a revised and improved version of the Bloom taxonomy and with competency models.

Although Bloom's (1956) foundational system has received a lot of criticism, its revised version continues to be widely used in developing educational goals and evaluation criteria. The lower three levels (*knowledge*, *comprehension* and *application*) of Bloom's systematic and hierarchical system, which established the taxonomic approach in the field, still appear in current theoretical frameworks, albeit with some minor modifications in terminology (e.g., *knowledge/recall*; *comprehension/understanding*) or interpretation. The criticisms appearing in the literature mainly concern the interpretability and discriminability of higher-order reasoning processes, i.e. analysis, synthesis and evaluation, and the connections between them. The model of Anderson and Krathwohl (2001), for instance, inverts the order of evaluation and synthesis, which the authors call creating. For Madaus et al. (1973) analysis and synthesis, for Huitt (2004) synthesis and evaluation, and for Johnson and Fuller (2006) all three processes are treated as activities of the same level of difficulty. Johnson and Fuller (2006, p. 121) also create a new category at the top of hierarchy, which they call higher application.

The IEA studies rely on a system developed from the Bloom taxonomy. The cognitive domain of the First International Science Study (FISS)

8 Downloaded on: 9 July 2008.: http://www.lifescied.org/cgi/content/full/1/3/63

and the Second International Science Study (SISS), for instance, consisted of knowledge, understanding, application and higher-order reasoning processes (Báthory, 1979; Commbers & Keevs, 1973). The three cognitive categories of the 2003 and 2007 cycles of the IEA-TIMSS studies cover essentially the same processes, albeit using different terminology. Bloom's foundational concepts are reflected in the category titles *Factual knowledge/Knowing* and in the contents of the categories *Conceptual understanding/Applying* and *Reasoning and analysis/Reasoning,* the latter of which covers higher-order processes (Mullis et al., 2001, pp. 37–70; 2005, pp. 41–77). Most of the processes included in these three categories[9] can be found in the conceptual framework of every IEA-survey. *Application/Applying* is the mid-level category of the cognitive domain in the FISS, the SISS, the 2007 assessment and the data collection scheduled for 2011 of the TIMSS studies (Commbers & Keevs, 1973; Keeves, 1992a; Mullis et al., 2005, pp. 41–77; 2009, pp. 88–89).

The spread of the cognitive approach and the shift in the approach to literacy are indicated by the fact that in the 2003 and 2007 cycles of the TIMSS studies and also in the 2011, the proportion of items assessing factual knowledge (the comprehension of simple and complex information and the knowledge of facts) has decreased significantly (from 69-70% to 30%). New types of tasks appeared, such as drawing conclusions, generalisation, the justification of explanations, the validation and evaluation of solutions, and listing of examples (see B. Németh, 2008, Tables 5 and 6; Mullis et al., 2009, p. 50). The shift in the interpretation of knowledge also manifests itself in the appearance of categories such as scientific inquiry, the communication of scientific results, recognising scientific evidence, understanding the interactions between mathematics and technology, and formulating conclusions in the three most recent TIMSS studies (Mullis et al., 2001, p. 69; 2005, p. 76; 2009, pp. 88–89). These categories are interpreted in a similar way to their counterparts in the OECD PISA programs, but they have little weight in TIMSS (Olsen, 2005, p. 26).

9 *Factual knowledge/Knowing*: e.g., knowing and using facts, information, correlations, tools and processes, understanding correlations − *Conceptual understanding/Applying*: e.g., understanding correlations, recognizing correlations, phrasing explanations − *Reasoning and analysis/ Reasoning*: e.g., interpreting processes, analyzing and solving problems, implementing assessments, etc.

In the PISA program, the cognitive domain of the knowledge to be measured is made up of a system of competencies. In the first two cycles, where a full coverage of literacy was beyond reach because of the limited resources, the cognitive domain termed *Scientific process* touches selectively upon the processes of the application of scientific thinking and knowledge, without attempting to construct comprehensive levels. The domain lists activities such as *Interpreting scientific concepts, phenomena and evidence*; *Drawing or evaluating conclusions*; and *Understanding scientific investigations* (OECD, 1999, p. 62; 2003, p. 137). The 2006 cycle, where scientific literacy is in special focus, includes three major competency categories: (1) *Identifying scientific issues*, (2) *Explaining phenomena scientifically* and (3) *Using scientific evidence*.

The National Educational Standards (NBS), which rely on a so-called normative competence model and conform to the German approach to literacy, characterise target competencies and thinking processes based on four categories of competency: subject knowledge, the application of epistemological and methodological knowledge, communication and judgment (Schecker & Parchmann, 2007).

The structure of the Australian NAP-SL contains elements similar to other national standards, but it is rooted in different theoretical considerations, distinguishing three categories:

"Strand A: formulating or identifying investigable questions and hypotheses, planning investigations and collecting evidence;

Strand B: interpreting evidence and drawing conclusions from their own or others' data, critiquing the trustworthiness of evidence and claims made by others, and communicating findings;

Strand C: using science understandings for describing and explaining natural phenomena and for interpreting reports about phenomena". (MCEETYA, 2006, pp. 3–4)

These three categories cover the five components of scientific literacy specified in the PISA surveys: (1) recognising scientific questions and evidence, (2) formulating, evaluating and communicating conclusions and (3) demonstrating an understanding of concepts (MCEETYA, 2006; OECD, 1999).

Each of the three categories is broken down to six levels of difficulty, the theoretical background for which is provided by Biggs and Collis'

(1982) *Structure of Observed Learning Outcomes* (SOLO) taxonomy, a qualitative assessment model based on the cognitive development theory of Piaget (1929). Biggs and Collis (1982) started with the assumption that the development of concepts and competencies has natural, age-specific stages building upon one another. Qualitative and quantitative changes, an increase in the level of understanding, and changes in the complexity of structure are all reflected in the performance of the student. The model classifies the quality of answers in terms of complexity and abstraction into five levels analogous with the cognitive developmental stages[10] of Piaget (1929): pre-structural, unistructural, multistructural, relational and extended abstract levels (Biggs & Collis, 1982; Biggs & Tang, 2007).

Distinguishing between concrete and abstract manifestations of the middle three levels (simple, complex and inter-related) of the SOLO taxonomy, NAP–SL specifies six levels of development among students in grades 1 to 6. These are the following:

Level (1): *concrete unistructural*: concrete simple answers in a given situation;

Level (2): *concrete multistructural*: concrete complex answers in different unrelated situations;

Level (3): *concrete relational*: concrete inter-related answers, generalisation;

Level (4): *abstract unistructural*: the use of abstract conceptual systems in a given situation;

Level (5): *abstract multistructural*: the use of abstract conceptual systems in different unrelated situations;

Level (6): *abstract relational*: the use of abstract conceptual systems in generalisation. (MCEETYA, 2006, pp. 81–82)

The Context of Assessment

In this day and age, it is an ever growing economic and social requirement to possess knowledge, acquired at school and elsewhere, that can be successfully deployed in real-world situations. Empirical studies sug-

10 Sensorimotor, preoperational, concrete and formal

gest, however, that the traditional institutional science education reliant on the 'pure science' of the curriculum cannot equip more than a few students with the kind of knowledge that is useful in everyday life (Calabrese Barton & Yang, 2000; Rennie & Johnston, 2004; Roth & Désautels, 2004; Ryder, 2001). Most students obtain that knowledge through personal experiences in situations involving issues of science outside of the school environment (Aikenhead, 2006; Rennie, 2006). The frequently experienced difficulties with the everyday applicability of classroom knowledge mostly stem from the dissimilar nature of the situation of acquisition and the situation of application (Csapó, 2002). During the learning process, human reasoning and acting adapt to the environment (Clancey, 1992), and the knowledge component (knowledge, skill, ability) to be acquired and its context together form a memory trace during the course of information processing (Wisemann & Tulving, 1976). Wisemann and Tulving (1976) have found evidence that the activation of memory traces is influenced by the relationship between the stored information and the information accessible at the time of recall, i.e., the degree of similarity between the context of learning and the context of application (Tulving, 1979). That is, the activation of knowledge is easier in known/familiar situations corresponding to the situation of acquisition than in an unfamiliar context with no mental representation in memory. The situational, context-dependent nature of knowledge (Clancey, 1992) in some cases facilitates and in other cases inhibits its applicability in different problem situations (Schneider, Healy, Ericsson, & Bourne, 1995). Decontextualised classroom learning devoid of hands-on experiences (may) cause difficulties with the understanding of school knowledge and its application outside the classroom (Csapó, 2001). The standards of operational knowledge/literacy need to specify the context of application as well.

While the taxonomisation of the content and cognitive domains of the knowledge taught and expected to be acquired are rooted in traditions of decades (see e.g., Anderson & Krathwohl, 2001; Báthory, 2000; Beaton et al., 1996a; Commbers & Keeves, 1973; Kloppfer, 1971; Mullis et al., 2001; 2005; 2009), we rarely find a detailed description of contexts. Most standards of content and evaluation characterise the circumstances of knowledge application with attributes such as new, known/unknown, lifelike, realistic, authentic, real and everyday without naming explicit parameters. In Australia, for instance, assessments are carried out using authentic tasks set in lifelike contexts at every level of cognitive process and conceptual category in all three strands of literacy (MCEETYA, 2006, pp. 3–4), but no detailed context taxonomy has been developed so far. Anderson differentiates between applications in familiar versus unfamiliar situations, and calls the former *executing* and the latter *implementing* (Anderson, 2005, p. 9). Certain taxonomies break down the application level of cognitive behaviour to subcategories, specifying the application conditions and context of the given content. In the first handbook on evaluation, for example, Kloppfer (1971, pp. 561–641), identifies three subcategories of applying scientific knowledge and methods, the application of new problems in a few and distinct areas of science, and in areas beyond science and technology.

At an international level, the first attempt to assess the application of scientific knowledge by means of tasks representing everyday situations was made in 1995, in the first IEA-TIMSS study[11]. However, a systematic description of the circumstances of knowledge application, the development of a differentiated system of *contexts* and its integration into the parameters of measured knowledge first appeared at the turn of the millennium only, as part of the scientific literacy assessment of the OECD PISA program.

In line with the definition of literacy, the contexts used in the OECD PISA surveys can be classified into categories such as *Realistic,* or lifelike, and *Unknown,* or different from the learning situations at school, and represent real-world situations related to science and technology (OECD, 2006). The OECD PISA program uses a two-dimensional taxonomy. One aspect of constructing the task contexts is provided by pertinent topics in science and technology and current issues related to health, natural resources, the environment and the dangers and limits of science and technology. The second aspect of constructing the task contexts is given by situations representing problems related to personal (self, family, peer groups), social (the community), or world-wide issues[12] (OECD,

11 In later IEA-TIMSS studies, the measurement of scientific knowledge is again dominated by scientific terminology, and common situations as task contexts are no longer typical.

12 In the 2000 and 2003 surveys, questions on the history of science and technology were also included.

2006, p. 27). PISA 2006 assesses scientific competencies in contexts that play a real role in maintaining and improving the living standards of individuals and of the community. When selecting the task contexts, a further consideration was that the task situations should be familiar, interesting and important for the students of all participating countries (OECD, 2006, pp. 26–28).

Summary

The literature in education theory offers a barely manageable diversity of approaches to literacy. The notion of scientific/science literacy representing the basic goals, principles and tasks of science education has no commonly accepted interpretation (Bybee, 1997b; DeBoer, 2000; Laugksch, 2000; Roberts, 2007). The current frameworks for the content of science education and its assessment are individual systems constructed with the implicit (e.g., the IEA studies) or explicit (e.g., the Australian NAP-SL, or the German NBS) use of theoretical models. These theoretical models describe scientific knowledge/literacy in terms of the expected cognitive and affective behaviour of educated people. Some of the models characterise the quality of literacy with reference to competences (e.g., Gräber, 2000), and to the increasingly complex processes of the literacy manifestations of the various developmental levels evolving through the organisation of thinking (e.g., Bybee, 1997a; Shamos, 1995),

According to comprehensive literature reviews (see e.g., Aikenhead, 2007; Jenkins, 1994; Laugksch; 2000; Pella, O'Hearn & Gale, 1966; Roberts, 2007) the general expectations of the various approaches differing in their perspectives, emphasis and structures are similar and construct their models from a shared set of elements and with essentially the same considerations in mind. One point of agreement is, for instance, that the scientific knowledge taught and expected to be acquired must have both individual and social relevance. Also, there is a broad consensus that scientific literacy is a complex, multidimensional system of knowledge (Roberts, 2007) that comprises

– the knowledge of nature, familiarity with, the understanding and the application of the major concepts, principles and methods of science;
– recognition of the values, nature, goals and limits of science;

– a structured system of thinking processes, and the competencies needed for application;
– scientific ways of thinking;
– scientific interests and attitudes (Hurd, 2003; Jenkins, 1994).

The curriculum and evaluation standards used in practice share the feature that the metaphorical use of the concept of *scientific/science literacy,* and the generalised definition of literacy are supplemented by less universal descriptions (Holbrook & Rannikmae, 2009). The detailed goal specifications define the knowledge expected to be acquired and intended to be assessed at its different levels of development and organisation in terms of the three components determining its applicability: content 'What should be known?', thinking 'How should it be known?' and context 'Where, in what context should it be known?'. These three parameters provide the basis for the theoretical frameworks even if they are structured according to varied principles and formulated using different terminologies.

In science standards, context usually refers to science-related situations outside of the classroom where prespecified knowledge (content) has relevance. Context tends to be a broad category characterised by adjectives such as unified, everyday, real, and lifelike. A differentiated description of the context of knowledge application and its multidimensional organisation (issues and problems in personal, social and global contexts) only appear in the OECD-PISA program (OECD, 2006).

In the theoretical frameworks of science education and the assessment of knowledge/literacy, the cognitive processes expected to be acquired and intended to be measured are structured along different cognitive taxonomies and competencies. There are behavioural patterns that appear in several frameworks. Processes shared by most of the standards, regardless of the diversity of their theoretical backgrounds and their terminologies, include understanding, application, familiarity with and use of the methods of science, the description and explanation of natural phenomena, scientific communication, the drawing of conclusions, etc.

The various approaches to literacy mainly differ in their views on content. The method of structuring knowledge and the choice of major categories depend on the interpretation of the relationships between the different fields of science (disciplinary versus integrated approach) and on the evaluation of the role of science in education. The choice between a disciplinary, interdisciplinary or multidisciplinary approach to science is strongly influenced by national characteristics, cultural traditions, educational traditions and current goals. With respect to the interpretation of the interactions between the different fields of science and their relationship to other disciplines there are two opposite poles among the curriculum and evaluation standards (Roberts' 'Visions', Roberts, 2007). One pole is represented by approaches focusing on traditionally interpreted science disciplines (e.g., the German NBS/Schecker & Parchmann, 2006) while the other pole is represented by views integrating natural and social sciences (e.g., Taiwan: Chiu, 2007; Israel: Mamlok-Naaman, 2007). The majority of approaches integrate various science disciplines in different ways and at different levels.

To our knowledge, no explicit model of scientific literacy is offered in the Hungarian research literature or in documents of education policy. The picture emerging from the 2007 version of the National Curriculum, the various curriculum frameworks and the school-leaving examination standards suggest that in Hungary, science education is largely discipline-oriented in terms of its approach, methods and structure. In grades 7 to 12, teaching is organised along the traditional academic subjects of Biology, Physics, Geography and Chemistry representing the traditional fields of science. Although the school subject *'Environmental Studies*' taught in grades 1 to 4 and the subject *'Nature Studies*' taught in grades 1 to 6 cover the four major disciplines, the integration is only a matter of form, as the different fields of science are clearly separated in the subject syllabi. The dependence on individual disciplines is also reflected in the characteristics of the knowledge taught.

The theory-oriented education that follows the logic of the different fields of science is efficient in a narrow section of the student population, as has been demonstrated by the performance of Hungarian scientists and engineers and the successes achieved at student Olympics. There are several signs indicating that the high-quality disciplinary and academic knowledge that can be acquired in Hungarian schools has rather weak personal and social relevance and fails to equip the majority of students, those not intending to pursue a scientific career, with the kind of knowledge they need to cope in the real world (e.g., B. Németh, 2003; Martin et al., 2008). According to the PISA studies, in Hungary students' applicable knowledge of science is at an average level in an international context and a growing proportion of our students perform poorly (e.g., B. Németh, 2003; Martin et al., 2008; OECD, 2010).

To move on, we need to reconsider our own approach to literacy taking international experiences into account, and seeking ways of incorporating them into our educational traditions. In order to develop a model of literacy offering knowledge that satisfies the expectations of our age and can be deployed by ordinary citizens in their everyday lives, several factors need to be considered. The model of literacy specifying the goals and guiding principles of science education should offer knowledge of social and personal relevance accessible to everyone; it should adopt the latest widely accepted results of research in psychology and education sciences, encourage an interest in science and conform to modern international trends, while at the same time building on the positive traditions of Hungarian education as the international experiences are incorporated.

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3

Disciplines and the Curricula in Science Education and Assessment

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Introduction

Science education has – especially since the mid-twentieth century – been dominated by the disciplinary approach, in which the scientific knowledge to be taught is organised according to separate disciplines. This approach has deep roots in Hungary and although since the 1980s efforts have been made to integrate the traditional disciplines and place a stronger emphasis on social relevance in the curriculum, the discipline-centred approach to science education still remains dominant in practice. The curriculum structure, the methods of teaching, learning organisation and assessment have all been heavily influenced by this view. The method of instruction that has become most-widely established is a teacher-centred method that focuses on the transfer of knowledge in a unidirectional process pointing from the expert teacher towards the learner as a passive recipient. In this model the assessment of the acquired knowledge stays within the context of the classroom and little emphasis is placed on issues such as the applicability and transferability of knowledge.

The objectives of science education are, however, different now from what they used to be. With the expansion of education more and more students are exposed to science education for a longer period of time. There is a growing need, therefore, for socially relevant knowledge and the development of scientific literacy in addition to the transfer of disciplinary knowledge. Bybee and Ben-Zvi (1998, p. 491) define the goal of science education as the intellectual development of an individual; assistance with their choice of profession and career; the sustainment and development of public order and economic productivity; the empowering of citizens to be scientifically and technologically literate; and the sustainment and development of scientific research, the transfer of scientific achievements and positive attitudes towards scientific research to future generations. To be able to achieve these complex goals and implement changes it is essential to reconsider the content of the curriculum and educational methods. A revision is all the more timely as science instruction at our schools is fraught with problems.

Hungarian science education, with its disciplinary approach, achieved major successes in the 20th century and was considered internationally outstanding up to the late 1980s. The system was especially successful in nurturing talent and produced excellent young scientists with a prominent level of knowledge even in an international context. In recent years, however, there has been a steep decline in the proportion of students having a high level of scientific knowledge albeit the average performance of Hungarian students is close to the international average as measured by international surveys (the International Association for the Evaluation of Educational Achievement Trends in International Mathematics and Science Study [IEA TIMSS] and the Organisation for Economic Co-operation and Development Programme for International Student Assessment [OECD PISA] surveys). The results also reveal that performance varies as a function of the nature and context of the assessed knowledge. Our students achieve better results in tasks that require the recall of classroom science and factual subject knowledge while they show poorer performance in tasks that require scientific reasoning, the use of empirical evidence or drawing conclusions (for a detailed overview of the Hungarian results of the international and national science surveys see B. Németh, Korom, & Nagy, 2012).

Studies analysing students' scientific knowledge have also pointed out that the expert knowledge emerging as a result of the discipline-oriented approach to education is overly specialised and mostly benefits students preparing for a career in science. There are, however, concerns with even the quality of this expert knowledge acquired at secondary schools. Recent studies assessing the skills of students applying to enrol in higher education courses in science or engineering reveal that a substantial share of these students do not have the basic subject knowledge required for higher education studies (Radnóti, 2010; Radnóti & Pipek, 2009; Revákné & Radnóti, 2011).

It is of major concern that not even students preparing for a science career show a genuine interest in science subjects and there is only a weak correlation between the popularity of these subjects and the choice of further studies. Even primary school students show a substantially less positive attitude towards Physics or Chemistry than towards other subjects and the popularity of these two science subjects declines further in secondary school. Biology and Geography also lose some of their appeal over the school years but still remain among the more popular subjects (Csapó, 2004a; Papp & Józsa, 2000). There has also been a drop in the appeal of a career in science as a substantial proportion of students do not consider the science syllabus to be relevant to their lives and find it difficult to relate scientific knowledge and activities to their everyday experiences (Józsa, Lencsés, & Papp, 1996; Nahalka, 1999; Papp, 2001; Papp & Pappné, 2003).

The situation in Hungary is in line with international trends. Based on an analysis of the situation of science education by an expert group set up by the *European Commission*, the *Rocard Report* (Rocard et al., 2007) drew attention to the disturbing fact that the proportion of students majoring in science subjects in higher education has decreased over the past decades in several countries around Europe. An especially low level of interest in Science, Technology and Mathematics is observed among women, and this is at a time when our knowledge-based society needs a substantially greater number of scientists, mathematicians and engineers and scientific literacy should be an integral part of general knowledge.

It is also becoming increasingly apparent that school curricula cannot keep up with the extremely rapid development of science and technology, and it is impossible for schools to include everything in their teaching. A better approach would be to equip students with a robust knowledge base that prepares them for independent learning, the processing of new information and the further improvement of their skills after leaving school. A revision of the content of school science curricula and a fresh approach to the role and significance of discipline-oriented knowledge are also urged by the results of psychological research of the past decades. Recent studies in cognitive and educational psychology concerning the organisation and acquisition of knowledge draw attention to the differences between learning in a natural versus in a school environment, and to the effects of naive beliefs and experiences outside of the school on the acquisition of scientific knowledge. These results suggest that the discovery of the world, the processing of the evidence accumulated by science and the acquisition of abstract conceptual frameworks are complicated processes that often require the reorganisation of students' existing knowledge.

This chapter discusses the role of disciplinary or specialised content knowledge in science education. We start with an overview of the dominant trends in science education and the evolution of its goals. Next, the results of research in cognitive psychology are summarised in relation to the organisation of knowledge and to information structure and typology. The third section concludes research on conceptual development and conceptual change. The fourth section discusses expert knowledge and its development, the process of acquisition and fine-tuning of expert schemas, and the question of the applicability and extensibility of expert knowledge. Sections 5 and 6 look at the components of scientific knowledge that are basic to scientific literacy according to the assessment frameworks of international science surveys and to various science curricula and content and assessment standards around the world. In these sections we also discuss the issue of knowledge component selection. The final section of this chapter considers questions of education theory in connection with disciplinary knowledge: how to transmit knowledge effectively and promote its meaningful acquisition, comprehension and transferability; and in what way the diagnostic assessment of a knowledge system can contribute to the process of teaching and learning.

Hungarian and International Trends in Science Education

The history of science education and the various approaches to curriculum development have been extensively analysed in both the international and the Hungarian literature (see e.g., B. Németh, 2008; Báthory, 1999;

Bybee & DeBoer, 1994; Comber & Keeves, 1973; Csapó, 2004b; DeBoer, 1991; Nahalka, 1993; Wallace & Louden, 1998). Relying on these studies, the most important trends are summarised here and the processes observed in Hungary are placed in the context of international trends.

According to Bybee and Ben-Zvi's (1998, p. 489) survey, three broad goals have emerged in the history of science education: the acquisition of scientific knowledge, the learning of scientific procedures and methods, and the understanding of the applications of science, especially the recognition of connections between science and society. The emphasis has shifted between the goals several times in the past five decades and the terminology describing them has also varied over time. Scientific knowledge, for instance, has been referred to as facts, principles, conceptual schemas or major themes. Scientific procedures have been variously termed scientific methods, problem-solving, scientific inquiry and the nature of science. For a while, no clear distinction was made between knowing about the processes of science and doing scientific investigation. Finally, the goals related to the applications of science have appeared under the titles of life adjustment and Science-Technology-Society (STS). In what follows, the evolution of these goals is outlined with reference to major periods and curriculum reforms in the history of science education, highlighting changes in the role and nature of knowledge and in the disciplinary approach.

The components of scientific knowledge (arithmetic, geometry and astronomy) were already present among the seven liberal arts in the Middle Ages, but the systematic instruction of science disciplines appeared only much later. The roots of science education go back to the first half of the 1800s in Western Europe and to the second half of the 1800s in the United States of America. In the beginning, the teaching of scientific knowledge was a feature of higher education, and it was later gradually incorporated into secondary and primary school programmes (Mihály, 2001). The science curriculum remained descriptive until the first half of the 20th century limited to the superficial characterisation of natural phenomena subject to direct experience. After World War II, however, technology began to advance at an accelerated pace, which led to the rapid accumulation of scientific knowledge. This technological development generated a demand for advanced science and engineering skills, which could not be provided by the science education of the previous era (Nahalka, 1993).

The period of the first major curriculum reform in the English-speaking world started after the 'Sputnik Shock' and lasted from the end of the 1950s to the middle of the 1970s, while in other countries it started in the 1970s and ended in the 1980s. It was at this time that science education was placed on a scientific basis and the curriculum was formulated to follow the structure of scientific disciplines. During this period science was interpreted as discipline knowledge, the acquisition of which in a school setting could provide the groundwork for new scientific discoveries. Wallace and Louden (1998) see the psycho-pedagogical foundations of this approach in Bruner's work, *The process of Education* (1960), which considered it important for students to be familiar with the abstract conceptual frameworks and structures of individual disciplines. During this period science professionals played a major role in curriculum development. New curricula and education programmes were meant to transmit knowledge that reflected the current trends in science and were regarded to be significant from the perspective of science disciplines. These curricula therefore followed the logic of science disciplines, adopted their professional terminology and represented their values. They emphasised the importance of professional precision and disciplinary understanding, the applicability of knowledge within the boundaries of the school subject and the development of skills required for scientific research and inquiry (Csapó, 2004b, p. 13).

The discipline-oriented curricula that emerged in the wake of the reform process, however, turned out to be unable to offer appropriate knowledge to students other than the few preparing for a career in science, and even this small group often simply rote-learnt what they were taught without actually understanding it. Science education faced the problem of structuring its content and establishing a coherent order of teaching the various subject areas, and the strict separation of the disciplines of science in the school environment was increasingly at odds with the new inter- and multidisciplinary research trends.

The intensive development of science generated a crisis in science education in most countries towards the end of the 20th century (Csapó, 2004b). The discipline-oriented approach could not keep up with the rapid flow of new results provided by scientific research and was similarly unable to keep track of the social effects of the development of science. The use and operation in everyday contexts of the new technological tools produced as a result of developments in science and engineering required less and less special skill, while at the same time the disciplinary knowledge provided by education proved to have little relevance for the general public.

There were various attempts to treat the symptoms of the crisis. Starting with the 1960s, a new initiative emerged within the science-centred approach, which gave rise to solutions of curriculum organisation and education methodology that eventually raised the issue of subject integration and unavoidably called for an analysis of the complex concept of integration (Chrappán, 1998). Integration is realised in a variety of different forms in the curricula of different countries and several international projects have been set up to map the connections between the various science subjects (Felvégi, 2006). The dilemma of integrated versus disciplinary science education continues to be a central issue today (Venville, Rennie, & Wallace, 2009) with convincing arguments both in favour and against.

In Hungarian public education the discipline-based system representing the expectations of the different fields of science was developed in the late 1950s and early 1960s (Szabó, 1998). As a result of interdisciplinary research outcomes, however, new efforts appeared shortly aiming to link the various disciplines in the science curricula and in a new generation of school textbooks. In the late 1960s physics textbooks were written under the leadership of Lajos Jánossy for the use of students in specialised secondary school classes, and an experimental programme was launched attempting to integrate mathematics and physics education. From the 1970s, a programme of integrated science education led by György Marx left its mark on science education in Hungary. The first attempt to introduce an integrated science course in Hungarian secondary schools was made in the early 1970s with the support of the Hungarian Academy of Sciences (MTA, 1976). Four basic principles (Laws of Motion, Structure of Matter, History and Evolution of Matter and Special Characteristics of Living Things) were specified as the content of scientific literacy.

The planned integrated subject was never introduced but the new science curriculum emerging from the curriculum reform of 1978 allowed sections linking elements of physics and chemistry, such as thermodynamics and chemical kinetics, to be included in physics and chemistry textbooks (Radnóti, 1995). Efforts to integrate were also apparent in the development of the school subject of Environmental Studies for primary school students, which introduced a few basic science concepts. Integration efforts increased once again in the 1990s. Integrated science subjects continued to be limited to the early phases of public education, however, Environmental Studies in Grades 1-4 was now followed by Nature Studies in Grades 5-6. In secondary education an integrated approach was only implemented in a few alternative education programmes (Veres, 2002a; 2002b; 2008). A basic prerequisite to the widespread introduction of subject integration is that teachers should have wide ranging knowledge and competence covering several science disciplines.

A different answer to the crisis of the disciplinary approach to education was offered by programmes that oversimplified the issue of knowledge application and tried to provide practical knowledge and teach everyday science with reference to a few arbitrarily selected everyday phenomena. These programs failed to fulfil expectations, as they could not develop well-organised, scientifically based knowledge. Currently, Home Science is included in some curricula as a multidisciplinary subject concerned with issues of lifestyle, household management and health (Siddiqui, 2008).

Curriculum development efforts focusing on scientific literacy (see Chapter 2) appeared in the 1970s. The various approaches to literacy incorporated the development of scientific skills and abilities and the question of the application of knowledge and its transfer to everyday life in addition to disciplinary content knowledge (Hobson, 1999). Wallace and Louden (1998) interpret the curricular science concept of this period (the 1970s and 80s) as relevant knowledge, where science is regarded as a tool of individual and social development that prepares students for participation in public life. The curriculum was designed within the framework of the 'science for all' movement to be accessible to everyone while at the same time providing a suitable foundation for those who would like to study science at a higher level (American Association for the Advancement of Science [AAAS], 1989).

Starting with the 1980s science curricula placed an even greater emphasis on the social and cultural implications of science, and a new movement, Science-Technology-Society (STS) emerged, which is a characteristic example of the humanistic approach to science education

(Aikenhead, 1994, 2006). STS emphasises the cultural, economic and social contexts of advances in science and technology. As a result of the STS movement some curricula included social issues related to the sciences such as global environmental problems of the Earth, the consequences of population growth and economic and technological development, or the effects of gene technology (Aikenhead, 1994). The basic principles and approach of the STS initiative and the social and ethical aspects of science education have also been discussed in the Hungarian research literature (Csorba, 2003; Havas, 2006; Marx, 2001). While the Hungarian National Curriculum also emphasises references to social issues in science education, the social effects of science research and the impact of technological development, which are the foundational principles of STS, have not been adopted by more than a few education programmes (Veres, 2008).

The STS initiative and the humanistic approach was (and still is today) a possible alternative to the traditional disciplinary approach. At the turn of the Millennium, however, a new, complex approach emerged combining educational and methodological knowledge and at the same time a research programme, which placed the teaching of school science on a new footing contrasting with the discipline-oriented approach. This new approach emphasises the process of education contrasting it with instruction, places the issues of science education in a social context and regards the scientific knowledge transmitted by the school as an essential component of the general literacy needed by every member of society, thus creating a bridge between science and education. The approach makes use of the results of psychological and education theoretical research on personality development, and the results of social and economic research analyzing the interactions between the school and society. The new view supports the meaningful, individual understanding of science issues, advanced knowledge transfer and the acquisition of knowledge readily applicable to new situations rather than the learning of specialised knowledge and its application in a classroom context. It emphasises the process of the cognitive development, the laws of development, the need to take students' motivations into consideration and the development of mental abilities (Csapó, 2004b, p. 13).

Wallace and Louden (1998) write about this period, which started in the 1980s-1990s and has continued to the present, that science curricula interpret science as imperfect knowledge and emphasise the evolution of scientific knowledge during learning as shaped by individual, social and cultural factors. The theoretical background of the approach comes partly from the post-positivist philosophy of science, the work of Lakatos (1970) and Popper (1972), according to which knowledge is not 'discovered' but rather 'construed' by a community of like-minded people. Another important theoretical foundation is the research in cognitive psychology aiming to characterise conceptual development. In order to understand the current goals of science education and our recommendations concerning the teaching of scientific knowledge, we summarise briefly the results of psychological and education theoretical research on the organisation of knowledge and conceptual development.

Organisation of Knowledge

In recent decades the focus of education theory research has shifted to the interpretation of the concept of knowledge and its various types, and to the analysis of internal (cognitive, affective) factors and external conditions influencing the development of knowledge (Csapó, 1992; 2001). The shift was primarily brought about by the advance of cognitive psychology starting in the second half of the 20^{th} century, through which we have gained a growing pool of information on the organisation of factual or declarative knowledge; the characteristics of imagery, propositions, mental models and schemas; the mental processes of reasoning; the development of and changes in expert knowledge; and the role of knowledge in reasoning (Eysenck & Keane, 1990; Mérő, 2001; Pinker, 1997; Pléh, 2001).

Mental Representation

Mental representation is the internal representation of the external world in either an analogue or a digital form. In case of analogue representation there is a strong correspondence between reality and its representation and the information gathered is stored without being converted into a different symbol system. That is how image is created, which may be of various types depending on the stimuli recorded by the receptors and the process of perception (e.g., visual, acoustic images, basic and complex images formed by the perception of different smells, tastes, pain, heat, body position and space). These mental images are not simply imprints of the external world; they are, instead, constructed and reconstructed from their elements and filled in with our conceptual knowledge as they are used or evoked.

The other type of representation is digital, where the original object and its mental representation are not alike, as the perceived stimulus is converted into a different symbol system, a linguistic code. Linguistic signs or symbols are assigned to the original visual image, sound, taste, etc., and propositions are constructed. Propositions are statements of fact showing the relationship between two concepts (e.g., the rose is a plant). Propositional representations capture the ideational content of the mind. They are language-like but not words, they are discrete, refer to individual objects, and abstract (may represent information from any modality), i.e., they constitute a modality-independent mental language. This class of knowledge is a system of verbal information or conceptual knowledge.

According to the classic interpretation of mental representation, the symbol processing paradigm, the process of representation involves the manipulation of symbols according to certain rules. There are now other models of knowledge representation in cognitive science. The most widely recognised theory relies on a connectionist model of information processing and posits distributed representations, which are composed of units below the level of symbols, i.e., are sub-symbolic. The theory maintains that the exceptional speed and flexibility of information management are explained by the distributed storage of information as a pattern of activation within the same network. Several researchers share the view that distributed representations describe the microstructure of cognitive representations, while the symbolic theory describes its macrostructure (McClelland, Rumelhart, & Hinton, 1986, cited in Eysenck & Keane, 1990, p. 260). As cognitive pedagogy and the research on conceptual development focus mainly on the macro-level, which is captured by the symbol processing approach, the theoretical framework described below details this approach.

Our knowledge system is thus composed of two different knowledge entities, images and concepts, with a network of transient or longer-term connections between these knowledge entities, which are created as a result of learning and reasoning. This network may have sections of structures of varied complexity constructed from various elements. If we look at a clearly defined topic, we may observe a hierarchical order in the structuring of concepts, but further complicated associations and links may form between distant concepts during the interpretation of a task or situation (Mérő, 2001). The size and the quality of our knowledge system are indicated by the number of units in the knowledge network and by the richness of connections. Our knowledge is continuously shaped, new elements are built in and new connections are constructed between existing elements as new associations are discovered throughout our lives. Our knowledge system varies by knowledge areas: it is richly structured in areas where we have a body of knowledge accumulated and polished through several years of varied experiences, and it is poorly structured in areas that we only have superficial experience of or where the knowledge acquired sometime in the past has not been recalled for a long time.

Concept Formation and the Organisation of Concepts

A concept is a category that allows entities forming a class in some way to be treated as a single unit of thought. In the system of József Nagy (1985, p. 153), a concept is a collection of elementary ideas representing a certain object. Since an object is defined by its properties, both of the object itself and its properties are represented by symbols. The symbol referring to the object is a name, while the symbol referring to the property is a feature. A name-feature association corresponding to a given object-property association may become an idea if the properties of properties are assigned features and/or we have an image of these properties (Nagy, 1985, p. 164). This is how an elementary concept is formed. As the next step of concept ontogenesis, further features are added, an elementary concept becomes a simple concept, and the object may be categorised, i.e., it can be decided whether the object is an exemplar of a given conceptual category or not on the basis of its features. When a concept becomes embedded in a conceptual hierarchy defined by certain conditions, it becomes a complex concept. General concepts that are relevant to life (e.g., matter, living organisms, society) may be developed into a complex concept by organising individual complex concepts of relevant objects constructed from different perspectives into a unified system. In this view, therefore, the development of the conceptual system is characterised by gradual enrichment and structuring.

Systematic education theoretical research on concept formation began in the 1970s building on the frameworks of philosophy and classic logical calculus, and making use of the achievements of semiotics. The main emphasis was first on the acquisition of the features of conceptual categories, generalisation within a category, the differentiation of categories and the structuring of the conceptual system (Bruner, 1960; Vojsvillo, 1978). In parallel with these efforts another approach emerged, which maintains that a concept not only reflects reality and the essence of a given entity but it is a knowledge component under constant development both in content and in its embeddedness in the conceptual system, which is in the service of certain psychic functions (Nagy, 1985).

Over the past three decades, research in cognitive psychology and developmental psychology has added several details to early theories in areas such as the process of categorisation, the mental representation of categories, the role of mental representation in behaviour and in the prediction of future behaviour, and the neurobiological and neuropsychological aspects of perceptual categorisation (Kovács, 2003; Murphy, 2002; Ragó, 2000; 2007a; 2007b). The results indicate that category boundaries are not always unambiguous or strictly defined, a characteristic that became known as 'fuzziness' in the literature. The features characterising a conceptual category and the exemplars of that category may be more or less typical, and a given object may even be an exemplar of several different categories depending on the context and the actual task or purpose. Concepts are therefore not simply retrieved from the conceptual network, but are constructed anew based on the stored properties as required by the given situation. Several concepts (mostly abstract concepts) are formed by creating a prototype on the basis of experiences rather than by learning the features characterizing the category. At a perceptual level, categorisation is already operative in infants but the identification of the features defining a category and the method of categorization undergo substantial changes during the course of cognitive development. The initial broad categories are narrowed down and divided into further categories while the features defining a category are replaced by others (Ragó, 2000).

Categorisation constitutes the foundations of the development of more complex conceptual systems. We would not be able to cope in everyday life without creating schemas based on our previous experiences to represent events, situations, ideas, relations and objects. A cognitive schema is a general knowledge structure applicable in a specific situation, a complex conceptual system, a culture-dependent unit of thought with a characteristic structure that is meaningful in itself. Schemas control or influence the perception and interpretation of different state-of-affairs, events and situations (Bartlett, 1932) while at the same time they are continuously modified as the new information is processed. Schemas interact with each other, are organised dynamically and form larger units (e.g., scripts, memory packages, semantic memory units) (Baddeley, 1997). It is cognitive schemas that organise our memory traces into thought. Only those memory traces play a role in our thinking which are linked to our existing cognitive schemas (Mérő, 2001, p. 175) and we only perceive what fits into our existing schemas.

The quality and level of organisation of knowledge systems vary between individuals and constantly change and evolve within any given individual. In cognitive psychology research the structure of simple hierarchical conceptual systems is explored through verification tasks (where the subject is asked to verify the truth of statements reflecting the conceptual hierarchy under investigation) and the structure of schemas is analysed through tasks involving the interpretation and recall of situations and texts. In education theoretic research, one of the most common methods of exploring knowledge and beliefs is based on clinical interviews as developed by Piaget (1929). Piaget originally interviewed young children to find out what kind of knowledge and beliefs underlay their answers when they gave an explanation for one or another phenomenon in the world. Besides the interview method, open-ended question tasks are also commonly used where students are asked to give a scientific explanation for various phenomena based on their everyday experiences. The level of interpretation of a given phenomenon can be determined by analysing and classifying the content of the answers, and comprehension problems and difficulties can be identified (Korom, 2002). The system of concepts stored in memory and the network of connections can be visualised with the help of various concept-mapping techniques, which may also assist the acquisition of new knowledge (Habók, 2007; Nagy, 2005; Novak, 1990).

Learning and Understanding

Besides the theoretical research on concept formation, in the 1970s another research direction emerged in education science in the English-speaking world. This approach emphasised the importance of comprehension and the encouragement of meaningful learning in sharp contrast to rote learning and memorisation. Learning is considered to be meaningful if individual concepts are not isolated in the student's mind but are functionally linked to existing concepts creating a coherent conceptual system with meaningful connections (Ausubel, 1968; Roth, 1990). Knowledge organised this way is easy to recall and apply, and may be expanded through the incorporation of new concepts and connections. The theory of meaningful learning gave rise to research efforts focusing on how students acquire and shape a hierarchically structured conceptual framework that enables them to analyse and interpret natural and social phenomena in their environment (Duit & Treagust, 1998). In recent approaches to meaningful learning, the question of self-regulated learning and learning strategies is also explored in addition to research on knowledge acquisition and comprehension (Artelt, Baumert, Julius-McElvany, & Peschar, 2003; B. Németh & Habók, 2006).

The theory of meaningful learning, the achievements of Piaget (1929, 1970) and Vygotsky (1962) and the results of research in cognitive psychology concerning knowledge representation are combined by the constructivist approach with learning, which emerged in the 1980s. The main basic tenet of constructivism is that the students are not passive agents but active participants in creating and shaping their own knowledge. Knowledge construction proceeds through arranging and fitting new information into old knowledge, which means that the quality of previous knowledge, the presence of preconceptions and beliefs influencing the discovery of the world, and the compatibility of the old and the new knowledge play a crucial role in the successfulness of learning (Glaserfeld, 1995; Nahalka, 2002a; Pope & Gilbert, 1983). Initially, research focus was placed on the exploration of the cognitive processes taking place in the psychic system of an individual during knowledge acquisition and on the various factors influencing these processes. Later, in the 1990s, the focus shifted to social cognition and the social aspects of knowledge acquisition.

Misconceptions and Naive Beliefs

Research into prior knowledge and beliefs influencing the acquisition of scientific knowledge was launched in the United States in the early 1970s using the theoretical work of Ausubel (1968). It started with the impact analysis of the curriculum reform following the 'Sputnik Shock' and soon became a popular area of education theoretical research worldwide. Initially, the outcomes of the science and mathematics curriculum projects were analysed to reveal whether they had led to meaningful learning and whether the students were able to apply the scientific knowledge acquired at school in explaining everyday phenomena. The results indicated that students' knowledge contained several elements that were incompatible with scientific views. These ideas, originating in naive generalisations and not being scientifically-based or reflected views directly contradictory to the position of science, were termed misconceptions (Novak, 1983).

Over the more than three decades that have passed since the initial studies, several thousand surveys have been carried out to assess students' knowledge in different subject areas and reveal the characteristics of misconceptions. It has been shown that the comprehension of scientific knowledge constitutes a problem in several fields. An especially large number of misconceptions have been identified in science, e.g., in connection with Newtonian mechanics, the structure of matter, biochemical processes, and heredity (Duit, 1994; Helm & Novak, 1983; Novak, 1987; 2005). The acquisition of scientific knowledge and its problems have also been investigated in a number of Hungarian studies (e.g., Dobóné, 2007; Kluknavszky, 2006; Korom, 2003; Ludányi, 2007; Nagy, 1999; Tóth, 1999). The analyses of misconceptions reveal that they are not isolated instances characteristic of a few individual students, i.e., their occurrence cannot simply be attributed to a lack of learning effort or the superficial acquisition of the subject matter. The same misconceptions appear across a broad range of student populations at different educational levels and of different nationalities.

Misconception research has also shown that student beliefs are similar to old theories known from the history of science (Wandersee, 1985). For instance, in the interpretation of the relationship between force and motion, Aristotelian physics and the medieval theory of impetus; in connection with the concepts of heat and temperature, the medieval caloric theory; in relation to evolution, Lamarck's theory; regarding the concept of life, the vis-vitalis theory; and in connection with heredity, the blood theory may be recognised in students' answers. These findings inspired a line of research in the philosophy and history of science that started out with Kuhn's theory of paradigm shift and explored the nature of conceptual changes appearing in the interpretation of certain themes and concepts (e.g., life, mind, diseases) from the first scientific explanations to the present, and compared the historical explanations with the ideas observed among students and adults (Arabatzis & Kindi, 2008; Thagard, 2008).

A breakthrough in the explanation of the occurrence and persistence of misconceptions came with research in developmental psychology on the principles of cognitive development (Gopnik, Meltzoff, & Kuhl, 1999). The reactions of a few month-old infants in various experimental situations suggest that when perceiving objects, infants make use of knowledge elements referring to the properties of those objects such as solidity, continuity and cohesion, or basic principles, such as "one object cannot be in two places at the same time", "objects fall if unsupported" (Spelke, 1991). Interviews with 4-7 year-old children also support the hypothesis that for infants, the discovery of the world is guided by innate, domain-specific basic biases deeply rooted in the cognitive system. Of the various knowledge areas, the literature has provided detailed descriptions of intuitive psychology, intuitive biology, which separates from intuitive psychology at the age of 4-6 years, the development of an intuitive theory of number and changes in the intuitive theory of matter (Carey & Spelke, 1994; Inagaki & Hatano, 2008).

The current state of research suggests that children interpret the various phenomena of the world constrained by their domain-specific biases and beliefs, as dictated by their own experiences, and create theory-like explanatory frameworks. Children's initial knowledge of the world has been referred to using a variety of terms (e.g., naive belief, naive theory, alternative conceptual framework, child science, intuitive theory, knowledge prior to education), but its descriptions converge. Children's beliefs rely upon the conclusions reached by the observation of visible objects and phenomena while lacking the knowledge and understanding of the real causes underlying these phenomena. Children's beliefs, therefore, represent a different – experiential – level of discovery of the world as opposed to the level of scientific explanations of the same phenomena, which rely on the tools of theory and model construction. Children's concepts and beliefs about the world naturally differ from scientific approaches, especially in the case of topics related to phenomena that cannot be understood on the basis of simple experience. Over the past few decades a large body of data has been collected in connection with the nature of child science, especially in the field of physics (Nahalka, 2002a; 2002b).

Children therefore do not start their public schooling with a tabula rasa but already have their naive beliefs explaining the world around them. Their existing knowledge is the starting point of learning and they need to harmonise this prior knowledge with the new knowledge they encounter in the classroom. Learning can proceed smoothly if there is no contradiction between the experiential and the scientific knowledge, since this allows the easy assimilation of knowledge and the uninterrupted expansion of the conceptual system (e.g., the properties of living organisms). Misconceptions are likely to appear when experiential knowledge cannot be reconciled with scientifically-based theories. Children's Aristotelian worldview of body motion (motion must have a cause, in the absence of a causal factor, the body will be at rest) cannot be translated into the theoretical model of Newtonian mechanics (motion does not stop spontaneously, in an inertial reference frame bodies not subject to forces are either stationary or move in a straight line at a constant speed). Children may overcome the interpretational problem arising when learning Newtonian mechanics in several ways. They may form misconceptions by mixing the old and new knowledge and by distorting the new information to a lesser or greater extent, or they may memorise the new information without meaningfully assimilating it into their existing knowledge system. A common phenomenon is that children separate everyday experiences from the knowledge learnt at school, thus creating parallel explanations of the world, an everyday and a classroom knowledge base.

When the naive theory and the scientific knowledge are incompatible, substantial cognitive effort is required for learners to be able to understand and accept scientific knowledge. They are forced to revise their naive theories and restructure their prior knowledge and conceptual system similarly to the way Piaget (1929) describes the accommodation of the cognitive system. The difficulties students have to face as they reconcile their everyday beliefs with the scientific views are comparable to the paradigm shifts observed in the history of science as described by Kuhn (1962), like, for instance, the recognition of the heliocentric world view in place of the geocentric world view, or the replacement of the Newtonian theory with the theory of relativity (Arabatzis & Kindi, 2008).

Theories of Conceptual Change

The literature approaches the process of reorganising learners' knowledge systems and the question of facilitating conceptual restructuring during the acquisition of scientific knowledge in a number of ways (for a detailed overview see Korom, 2000, 2005a). Posner, Strike, Hewson, & Gertzog (1982) regard conceptual change as the replacement of a set of concepts by another, which occurs as a resolution of the cognitive conflict generated by a clash between old and new concepts. During this process the students acknowledge the limits of their own conceptions and recognise the new concepts and explanatory framework as valid and useful. Other researchers (Chinn & Brewer, 1998; Spada, 1994) point out, however, that students are unable to erase or completely abandon and replace their preconceptions. These authors therefore maintain that education should focus on the management of multiple representations and the development of metacognitive strategies of knowledge acquisition. The same phenomenon may be represented at a number of different levels: schooling could build a higher, interpretative level on top of the initial experiential level. For this approach to succeed the differences between the various modes of discovering, the world must be understood and an ability to reflect upon our own knowledge and the learning process must be developed.

Analysing spontaneous changes during cognitive development, Carey (1985), a researcher in developmental cognitive psychology, differentiates between radical and less radical forms of restructuring. Vosniadou (1994) finds that conceptual changes are domain-specific, unfold over a relatively long period of time and require substantial cognitive effort. In order to overcome misconceptions, we need to revise basic beliefs that are firmly entrenched and fundamental to our interpretation of the world. It is difficult, for instance, to give up the belief that things are what they seem to be; or to accept that even though objects that have been dropped appear to fall at a right angle to the surface, the force of gravity in fact points towards the centre of the Earth in reference to the whole planet rather than downwards (Vosniadou, 1994). There are cases where a conceptual change involves children needing to revise their ontological classification of entities in the world. Heat, for instance, is initially classified as matter and when children learn that it is not matter, they need to move it to a different category and reclassify it as a process. Or plants are initially considered to be inanimate objects, and as children observe and learn about life functions and the defining criteria of life, they will realise that plants are living organisms and should be classified as such (Chi, Slotta, & de Leeuw, 1994). Research into the mechanisms of conceptual change is becoming more and more diverse. In addition to studies of spontaneous and education-induced restructuring, it now covers cognitive factors influencing conceptual change such as students' epistemological and metacognitive knowledge (Vosniadou, 2008). Besides the 'cold conceptual change' approach focusing on cognitive variables (Pintrich, Marx, & Boyle, 1993), the past decade – with its focus on the social constructivist approach building on the works of Vygotsky – gave rise to studies of the effects of affective (Murphy & Alexander, 2008) and sociocultural factors (Caravita & Halldén, 1994; Halldén, Scheja, & Haglund, 2008; Leach & Scott, 2008; Saljö, 1999).

The role and significance of content knowledge in learning has been re-evaluated due to the results of cognitive science. The emphasis has shifted from the reception and reproduction of information to the development of a well-organised and efficient knowledge system, which is a prerequisite to the operation of higher-order cognitive functions.

Expert Knowledge

Some fundamental questions of research in cognitive psychology and artificial intelligence are how knowledge is structured, what makes reasoning flexible and efficient and what enables individuals to respond quickly and adaptively when faced with various situations and tasks. Cognitive psychologists treat human learning as information processing and have used computers first as an analogy and later as a tool to model the processes of human information processing and reasoning.

Expert knowledge has been studied in several areas: the cognitive performance and problem-solving strategies of novices and experts have been compared first in the domain of chess (Simon, 1982), and then in various other areas such as medical diagnostics, physics, chemistry, scientific inquiry and problem-solving (Chi, Feltovich, & Glaser, 1981; Hackling & Garnett, 1992). The results indicate that novices and experts do not differ significantly in terms of the basic processes of information-processing (e.g., storage in short-term memory, speed of identifying and searching information). They do differ, however, in the quantity of stored information and the structuring of their knowledge. Experts have significantly more knowledge and, what is even more important, their knowledge is structured, while novices' knowledge is composed of pieces of information in isolation. Experts think in terms of schemas and structures and use more efficient strategies of structuring, managing and recalling information. While an amateur chess player knows only a few hundred schemas, a chess master knows tens of thousands. The chess master's schemas are more complex with a complicated network of connections between them enabling the expert to treat positions and combinations as parts of a larger system rather than isolated examples. This explains why a novice sees several sensible possibilities when a master sees only a few in a given state of the game (Mérő, 2001). The differences observed for chess players are also valid for other areas of expertise and professions. An expert of a profession knows tens of thousands of schemas related to their area of expertise. The cognitive schemas of an area of expertise are specific to that area and give rise to a level of performance that seems unimaginable for someone inexperienced in that area.

A lot of learning – at least ten-fifteen years of work – is needed to reach the level of a grandmaster. In terms of the number of schemas László

Mérő (2001, p. 195) distinguishes four levels of professional development. The first level is the novice level, where an individual may have only a few dozen schemas and their reasoning and problem-solving strategies characteristically involve the application of everyday schemas. The novice is not familiar with professional terminology, their problem-solving is slow-paced, they cannot grasp the problems, recognise relationships or explain what it is they do not know. The next, advanced level can be reached after a few years of learning. By this time the individual possesses a few hundred simple schemas related to their profession. They have some difficulty with professional terminology, the quality of their professional communication is variable and their strategies in problem-solving employ an inconsistent mixture of professional and everyday schemas, as they do not have sufficient professional knowledge to grasp the problems to be solved. Their awareness of their professional knowledge has changed relative to the novice level: They know what they do not know yet. The next level is that of a candidate master, which requires higher education and at least five years of learning. A candidate master (or expert) possesses a few thousand schemas, can use these schemas appropriately, their problem-solving follows the logic of the profession, their reasoning is rational, their professional communication is to the point and correct and they know exactly what they know and how they know it. The highest level of expertise, that of a grandmaster, is reached by few people, since in addition to a long period, ten or more years, of learning, it also requires special talent. A grandmaster possesses tens of thousands of complex schemas, their problem-solving is visual and synthetic, and their reasoning is intuitive. A grandmaster uses schemas that they cannot describe in words; they have a private language of thought. Their problem-solving is intuitive rather than deductive and they are able to grasp the essence of the problem and its solution. Their professional communication is deeply intuitive, informal and panoptical and uses analogies instead of professional arguments. With respect to metacognitive skills, grandmasters know what is right but do not know how they know it.

The various professions differ in terms of the period of time needed to reach an expert level. In the case of relatively abstract sciences (e.g., mathematics) maturation is faster than in the case of sciences closer to everyday schemas (e.g., biology). For the latter, extra time is needed to separate common schemas from professional schemas.

The acquisition of expertise is a cumulative process: our professional knowledge may be expanded throughout our life, which is why this type of knowledge is often compared to crystallised intelligence. Although the development of expert knowledge is not tied to any particular age period, the foundations of professional knowledge should be acquired at a young age (Csapó, 2004c). Looking at the levels of expertise development it can be seen that primary school education can take students to a novice level, while secondary education can take them to an advanced level of expertise. The disciplinary approach to education seeks to transmit the logic, approach and basic principles of a specific scientific field. Students have to learn several new concepts and facts. Learning is most likely to be successful in cases where the new knowledge fits the student's everyday schemas. If the new information is too abstract, far removed from the experiential level students are able to follow, and does not fit students' everyday schemas, a mixed system of scientific and commonsense knowledge will be created giving rise to misconceptions and comprehension problems.

Expertise is the sum of knowledge, skills and competencies specified by a given field that can only be applied in the context of that field (Csapó, 2004c). When someone becomes an expert in a field, they can quickly and easily solve the familiar tasks since an expert has ready-made schemas for various situations and is able to mobilise the acquired algorithms. While expertise is essential for high-quality professional activities, the professional schemas (e.g., the specialised knowledge of a surgeon, chess player or chemist) are of limited use in other professional areas or in everyday life. The disciplinary approach to science education lays the foundations of expert knowledge, which benefits students who wish to become candidate masters or masters of the field in the future. The question that arises is how to lay the foundations of expert knowledge and everyday scientific literacy at the same time, i.e., what knowledge and domain-specific abilities must be acquired and practiced in the course of studies.

Specialised Knowledge in Curriculum and Assessment Documents

In recent years the focus has shifted from expert knowledge to the development of scientific literacy. This does not mean that specialised or content knowledge have been marginalised; the shift, instead, involves a reallocation of emphases and a rethinking of learning objectives and the specialized contents as means of achieving those objectives. There are several approaches and models of scientific literacy (see Chapter 2), but all of them incorporate elements of disciplinary knowledge. In what follows a few examples of the properties and definitions of content knowledge will be presented based on curriculum and assessment documents.

Content Areas

In their list of the features of good education standards, Klieme et al. (2003, p. 20) mention, among others, subject-specificity and focus: standards should be tied to specific content areas and should clearly specify the basic principles of a given discipline or subject; and standards should focus on core areas rather than trying to cover the entire system of a given discipline or subject. Looking at the content-related aspects of a few science curricula, standards and assessment frameworks, we find that they do not provide a complete coverage of science disciplines. In some cases, the major content areas do not include every disciplinary area, and only a few topics are in focus within individual fields. The specialised topics matching the structure and logic of traditional science disciplines are often complemented by broader topics and principles reaching across the individual science disciplines.

The National Curriculum for England specifies four content areas in science: Scientific enquiry, Life processes and living things, Materials and their properties, and Physical processes.

The content specifications of The Australian Curriculum include the science disciplines of Biological sciences, Chemical sciences, Earth and space sciences, and Physical sciences, which are complemented by topics related to science: Nature and development of science, and Use and influence of science.

The Science and Technology Section (2007) of The Ontario Curriculum of Canada lists four strands of the study programme: Understanding Life Systems, Understanding Structures and Mechanisms, Understanding Matter and Energy, and Understanding Earth and Space Systems.

The US National Science Education Standards (NSES) of 1996 define eight Science Content Standards (National Research Council [NRC], 1996, pp. 103-108):

(1) The standard Unifying concepts and processes in science contain integrated schemas that take several years to develop and are expected to be completed by the end of formal science education (K-12). These broad knowledge areas are the following: Systems, order, and organization; Evidence, models, and explanation; Change, constancy, and measurement; Evolution and equilibrium; and Form and function.

(2) The Science as inquiry standards specify knowledge giving rise to Abilities necessary to do scientific inquiry and Understanding about scientific inquiry. A new dimension, "the processes of science", appears in these standards, which expects students to link processes/procedures with scientific knowledge and use scientific reasoning and critical thinking to understand science.

(3-5) The Physical science standards, Life science standards and Earth and space science standards specify science content knowledge in three broad areas. They focus on scientific facts, concepts, principles, theories and models that every student should know, understand and apply.

(3) Topics appearing in Physical science standards for Levels K-4 are Properties of objects and materials, Position and motion of objects; Light, heat, electricity, and magnetism. For Levels 5-8 topics are Properties and changes of properties in matter, Motions and forces, Transfer of energy. For Levels 9-12 they are Structure of atoms, Structure and properties of matter, Chemical reactions, Motions and forces, Conservation of energy and increase in disorder and Interactions of energy and matter.

(4) Life science standards cover the following topics for Levels K-4 are Characteristics of organisms, Life cycles of organisms, Organisms and environments. For Levels 5-8 they are Structure and function in living systems, Reproduction and heredity, Regulation and behaviour, Populations and ecosystems, Diversity and adaptations of organisms. For Levels 9-12: The cell, Molecular basis of heredity, Biological evolution, Inter-

dependence of organisms, Matter, energy, and organisation in living systems and Behaviour of organisms.

(5) Earth and space science standards for Levels K-4 focus on the following topics: Properties of earth materials, Objects in the sky, Changes in earth and sky. For Levels 5-8 they are Structure of the earth system, Earth's history, Earth in the solar system. For Levels 9-12 these are Energy in the earth system, Geochemical cycles, Origin and evolution of the earth system, Origin and evolution of the universe.

(6) Science and technology standards establish a connection between the natural and the built environment and emphasise the development of skills required for decision-making. As a complement to the abilities needed for scientific inquiry, these standards highlight the following abilities: identifying and articulating problems, solution-planning, cost-benefit-risk analysis, testing and evaluating solutions. These standards are closely related to other fields such as mathematics.

(7) The Science in personal and social perspectives standards emphasise the development of decision-making skills needed in situations that students as citizens will face in their personal lives and as members of society. The topics of these standards include Personal and community health, Population growth, Natural resources, Environmental quality, Natural and human-induced hazards and Science and technology in local, national and global challenges.

(8) History and nature of science standards state that studying the history of science at school helps to clarify various aspects of scientific research, the human factors in science and the role science has played in the development of different cultures.

Besides NSES, the development of the assessment frameworks of National Assessment of Educational Programs (NAEP) has also been greatly influenced by Project 2061 launched by the American Association for the Advancement of Science (AAAS). Two of the documents produced in the framework of the project had an especially great impact. Science for All Americans (AAAS, 1989) attempts to define the kind of knowledge that should be acquired by every American student by the end of secondary education, and the way science education could be reformed to meet the requirements of the 21st century and provide suitable knowledge not only for the present but also for the time when Hailey's comet returns in 2061. Benchmarks for Science Literacy (AAAS, 1993) specifies targets to be attained by the end of Grades 2, 5, 8 and 12. It lists twelve content areas: Nature of science; Nature of Mathematics; Nature of technology; Physical setting; The living environment; The human organism; Human society; The designed world; The mathematical world; Historical perspectives; Common themes; and Habits of mind. The developers of Project 2061 defined five criteria for the selection of scientific content: Utility, Social responsibility, Intrinsic value of the knowledge, Philosophical value, and Childhood enrichment.

A Framework for K-12 science education: Practices, crosscutting concepts, and core ideas (2011) is a new theoretical framework that identifies four content areas: Physical Sciences, Life Sciences, Earth and Space Sciences and Engineering, Technology and the Applications of Science.

The science standards of the Australian state of New South Wales (Board of Studies New South Wales of Australia, 2006) list the following content components: Built environments, Information and communication, Living things, Physical phenomena, Products and services and Earth and its surroundings. The science standards for Victoria state (The Victorian Essential Learning Standards [VELS]) group contents into only two categories: Science knowledge and understanding, and Science at work.

The education standards for Germany (Bildungsstandards für den Mittleren Schulabschluss, Jahrgangsstufe 10) provide guidelines for three science disciplines (biology, physics and chemistry) for Grade 10 of secondary education.

Hong Kong's *Learning outcomes framework* (LOF) specifies learning targets in the following six strands: Science investigation, Life and Living, The Material World, Energy and Change, The Earth and Beyond and Science, Technology, Society and Environment.

The international examples listed above show that the division and classification of the content knowledge of the disciplines of science vary between curriculum and assessment documents. The nature of the content categories reflects the interpretation of the goals and tasks of science education in a given country. Discipline-specific contents tend to be complemented by learning targets related to the nature and workings of science and to the relationship between knowledge and technology.

Basic Concepts and Principles

Several curriculum and assessment documents define basic concepts and principles with the aim of enabling students to acquire a modern scientific method way of thinking/perspective. The functions and contents of basic concepts and principles vary between countries to a great extent.

The Canadian curriculum (The Ontario Curriculum: Science and Technology, 2007) constructs a system of hierarchically organised basic concepts, principles, goals and expectations systematically characterising each topic (p. 6). The curriculum defines “Big Ideas” based on the fundamental concepts of matter, energy, systems and interactions, structure and function, sustainability and stewardship and change and continuity. The Big Ideas define goals related to three topics: (1) to relate science and technology to society and the environment; (2) to develop the skills, strategies and habits of mind required for scientific inquiry and technological problem-solving; and (3) to understand the basic concepts of science and technology. Each of the three goals leads to overall and specific expectations in the curriculum.

In the Understanding Life Systems strand, for instance, one of the “Big Ideas” for Grade 1 students within the topic of Needs and characteristics of living things is “Living things grow, take in food to create energy, make waste, and reproduce.” An overall expectation related to this “Big Idea” is that by the end of Grade 1 students will investigate needs and characteristics of plants and animals, including humans. One of the specific expectations states that by the end of Grade 1 students will identify environment as the area in which something or someone exits or lives.

In the US science education standards (NRC, 1996, pp. 103–108) – as was discussed above – the following basic concepts are defined by the first content standard (Unifying concepts and processes in science): Systems, order, and organization; Evidence, models, and explanation; Change, constancy, and measurement; Evolution and equilibrium and Form and function.

The theoretical framework prepared for the new US science education standards (A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas, 2011) defines complex concepts cutting across the boundaries of the various disciplines (pp. 61–62). The following concepts are listed: Patterns; Cause and effect: Mechanism and explanation;

Scale, proportion and quantity; Systems and system models; Energy and matter: Flows, cycles and conservation; Structure and function and Stability and change.

In addition to the crosscutting concepts, the framework also defines core ideas for each content category (Life Sciences, Physical Sciences, Earth and Space Sciences and Engineering, Technology and Applications of Science). Each core idea is assigned a label and a list of questions defining it, and the attainable knowledge related to the idea is described broken down into different age groups. One of the core ideas of Life Sciences, for instance, is that "Living organisms have structure and function that help them grow and reproduce." (Label: From molecules to organisms: Structures and Processes.) One of the questions of this core idea is "How do organisms live, grow, respond to their environment and reproduce?" (p. 101).

The German education standards define basic concepts in relation to individual school subjects. For physics, for instance, the basic concepts are matter, interaction, system, energy; for biology, system, structure and function and development; for chemistry, particles, structure and property, chemical reactions and energy transformation.

In the Austrian science education standards developed for upper secondary schools, subject content is presented as subject competency (Weiglhofer, 2007). It contains broad basic concepts such as Materials, particles and structures (the structure and properties of matter, from molecules to cells, from cells to organism); Interactions (chemical and physical reactions, metabolism, perception); Evolution and process (transfer/transmission, evolution, chemical technology, physical development, science and society); and Systems (periodical system of the elements, space and time, ecology).

The Science knowledge and understanding dimension of the science domain of the *Victorian essential learning standards* (VELS) emphasises the understanding of relationships in science. Students are expected to be familiar with the overarching concepts of science, understand the nature of the similarities and differences between living organism, and their sustainable relationship with each other and their environment. Students should know the properties of matter and understand the transformation of matter through chemical reaction. They should understand the concepts of energy and force and be able to use these concepts for the explanation of physical phenomena. They should know the place of the Earth in space and time and understand the relationships between the Earth and its atmosphere. Finally, they are expected to be able to distinguish microscopic and macroscopic levels in the examination of matter.

Basic concepts and core ideas fulfil a variety of functions in curriculum and assessment documents. They ensure that the most important factual information and skills are well-defined and systematically and purposefully developed in education, and they facilitate the development of a programme of clearly identifiable standards covering different age groups and topics.

The Organisation of Content in Hungarian Curricula and Standards

The Hungarian National Curriculum introduced in 1995 was the outcome of the curriculum reform process starting in the late 1980s. The Curriculum abandoned the previous school subject-based division and embraced an integrative approach where contents were organised into broader literacy categories. Detailed requirements were specified for each literacy domain and common cross-literacy requirements were also defined.

The 2003 amendment to the National Curriculum shifted the focus from the specific requirements to a set of special educational objectives. New, modern science education standards reaching beyond the traditional disciplines were added, such as the development of general, discipline-independent science concepts, processes and habits of mind; raising awareness of the relevance of science and scientific research to society; showing the internal and external conditions of the interdependence of science disciplines, the linking of knowledge systems; developing ideas about the relationship between scientific and technological development on one hand and social development on the other; and the reinforcement of structured student thinking through interaction. The domain of scientific literacy was renamed from “People and environment” to “People in the environment” and the content standards were reorganised into groups characterised by key concepts.

The new structure was kept in the 2007 version of the Curriculum and the key competencies in science and the goals of science education were defined in greater detail. The 2007 Curriculum groups scientific knowledge contents and targets into two domains of literacy: People in the environment and Our Earth – our environment. The knowledge, skills and competencies to be attained are organised not by disciplines but according to key concepts and topics for the different stages of education (Grades 1–4, 5–6, 7–8 and 9–12).

In the domain of People in the environment, educational tasks are defined for three subject areas: (1) Exploring the nature of science and scientific inquiry, the interactions between science, technology and society; (2) Scientific inquiry; (3) Exploring the living and non-living environment, which is divided into the sub-topics of Matter, Energy, Information, Space, Time and motion, Our home, Hungary, the Earth and the universe, System and Life.

The literacy domain Our Earth – our environment applies to Grades 5 and above and defines targets in relation to the following educational goals: (1) General tasks of development, (2) Information collection and analysis, (3) Orientation in geographical space, (4) Orientation in time, (5) Exploring environmental materials, (6) Exploring environmental interactions, (7) Exploring issues of the geography of Hungary, and (8) Exploring regional and global issues in geography. The Hungarian framework curricula are based on the national core curriculum and detail the contents of the literacy domains broken down to school subjects by school type and grade, also specifying the conditions of entering the next grade of school.

In Hungary, standards for the assessment of scientific knowledge were developed in the late 1970s for the first time, in connection with the revisions of the curriculum at that time (Victor, 1979; 1980; Zátonyi, 1978; 1979; 1980). A second version was prepared in the 1990s in relation to – eventually abandoned – plans to introduce a literacy test for 16 year-old students. These standards were developed under the direction of József Nagy at the Literacy Examination Centre and specified a lower and a higher level of assessment providing examples of tasks and assessment methods at each level (B. Németh & Nagy, 1999; B. Németh, Nagy, & Józsa 2001; Hajdu, 1998; Pótáriné, 1999; Zátonyi, 1998). At present, the most detailed set of learning standards is the document defining the knowledge expected of students taking their school-leaving examinations, which is organised by school subjects following the logic and topic areas of the given science discipline at two levels of difficulty, but also allows students to take an integrated science examination.

The Content Domains of International and Hungarian Science Literacy Surveys

The changes in knowledge conceptions and the re-evaluation of the role of science education and the efficiency of education are reflected in the assessment frameworks of international surveys in the past four decades. The following section briefly discusses the assessment frameworks of the science surveys of the International Association for the Evaluation of Educational Achievement (IEA), the International Assessment of Educational Progress (IEAP) – which is based on the American longitudinal survey series National Assessment of Educational Progress (NAEP), and the OECD PISA (Programme for International Student Assessment) programme. Of the three dimensions measured in these surveys (content, cognitive, context, see Chapter 2 for details), only the content dimension is detailed here through an analysis of the nature of science literacy contents, their structure and the relative proportions of subject areas.

The IEA Science Surveys

IEA was established under the auspices of UNESCO at the end of the 1950s. The launch of the surveys coordinated by the Association and carried out among students in Grades 3–4, 7–8 and occasionally in Grade 12 was motivated by questions of efficiency of the programmes developed in the first major curriculum reform of science education, and the need to test whether the curriculum targets had been achieved. The IEA surveys evaluate the efficiency of education systems with reference to the standards declared in the educational documents of the participating countries, i.e., the intended curricula of the countries are used as a starting and reference point. The surveys assess what has been attained relative to what was intended (Mullis et al., 2005; Olsen, Lie, & Turmo, 2001). In the assessment framework of these surveys, the system of scientific knowledge under assessment reflects the discipline-oriented approach and contains knowledge related to the fundamental principles and structure of scientific disciplines.

The First International Science Study (FISS) conducted in 1970-71 and the Third International Mathematics and Science Study (TIMSS) of 1994-95 were designed for subject pedagogical purposes and analysed the relationship between subject targets and students' performance. The Second International Science Study (SISS) was a "world curriculum study", while the repeat of the third study (Third International Mathematics and Science Study Repeat – TIMSS-R) and the 2003 (Báthory, 2003, p. 6) and 2007 cycles of Trends in International Mathematics and Science Study (TIMSS) were designed for trends analysis.

The thematic units of each of the survey cycles administered so far cover the four disciplines of science: Life science/Biology, Earth science, Physical sciences, which is divided into Chemistry and Physics for upper grades. These categories representing the scientific disciplines were complemented with topics related to knowledge about the nature of science in TIMSS 1995: Environmental issues and The nature of science. Later cycles included topics about science and scientific inquiry in varying proportions and with varying content. TIMSS 1999 covered topics in Environmental and resource issues, and Scientific inquiry and the nature of science, while the 2003 cycle included topics in Environmental sciences. The relative proportions of the four scientific disciplines have remained essentially the same over the years. Although in TIMSS 2003 and 2007 the assessed subject areas were more or less balanced, the survey series display a slight overall preference for Biology (or Life science) and Physics (B. Németh, 2008; Beaton et al., 1996; Keeves, 1992a, p. 64; Martin et al., 2000; Mullis et al., 2001, pp. 37–70; 2005, pp. 41–77).

In what follows the topic areas within the four fields for two age groups are detailed based on the 2007 wave of TIMSS. As shown in Table 3.1, the most important difference between the two grades is the lower proportion of Life science topics and the separation of Chemistry and Physics for Grade 8. The assessed topics within each field roughly correspond between the two age groups, but they are explored in greater depth and detail in questions designed for the upper grade.

Table 3.1 Knowledge domains and their distribution in TIMSS 2007 for Grades 4 and 8 (Mullis et al., 2005, pp. 41-77)

Grade 4	Grade 8
Life Science / 45% • Characteristics and life processes of living things • Life cycles, reproduction, and heredity • Interactions with the environment • Ecosystems • Human health	*Biology / 35%* • Characteristics, classification, and life processes of organisms • Cells and their functions • Life cycles, reproduction, and heredity • Diversity, adaptation, and natural selection • Ecosystems • Human health
Physical science / 35% • Classification and properties of matter • Physical states and changes in matter • Energy sources, heat, and temperature • Light and sound • Electricity and magnetism • Forces and motion	*Chemistry / 20%* • Classification and composition of matter • Properties of matter • Chemical change *Physics / 25%* • Physical states and changes in matter • Energy transformations, heat, and temperature • Light • Sound • Electricity and magnetism • Forces and motion
Earth science / 20% • Earth's structure, physical characteristics, and resources • Earth's processes, cycles, and history • Earth in the solar system	*Earth science / 20%* • Earth's structure and physical features • Earth's processes, cycles, and history • Earth's resources, their use and conservation • Earth in the solar system and the universe

The American NAEP Surveys

The NAEP Science Framework, the assessment framework of the US National Assessment of Educational Progress (NAEP), defined three components of knowing and doing science (Conceptual understanding, Scientific investigation and Practical reasoning) in three major fields of science (Physical science, Life science and Earth science) for the 1996–2005 period. Besides the three fields of science, the content framework covered the nature of science and three abstract themes: systems, models and patterns of change (Champagne, Bergin, Bybee, Duschl, & Gallagher, 2004).

The 2009 NAEP Science Framework was developed on the basis of several standards and assessment documents (National Standards, National Benchmarks, standards of individual states and the assessment frameworks of TIMSS and PISA). The three major fields of science (Physical science, Life science and Earth science) remained separate but the dimension assessing scientific activities and the application of knowledge (Science Practices) was redesigned. While in previous assessment points this dimension dealt with conceptual understanding, scientific investigation and practical reasoning, in the new version science practices refer to the identification of science principles and the use of science principles, scientific inquiry and technological design. The old content topic of the nature of science is now included with the use of science principles and scientific inquiry. The 2009 version does not use abstract concepts such as "models", "constancy and change" or "form and function", contents cutting across individual fields and the relationships between different disciplinary topics are, instead, characterised by the topic labels (e.g., Biogeochemical cycles in Earth and space sciences).

The IAEP Surveys

The two IAEP (International Assessment of Educational Progress) surveys conducted by the Educational Testing Service (ETS) were primarily related to the American national studies but to some extent were also influenced by the IEA theoretical frameworks. The first IAEP survey took place in 1988 with the participation of 6 countries (Canada, Ireland, Korea, Spain, the United Kingdom, and the USA). The mathematics and science attainment of 13 year-old students was assessed. The second IAEP survey, in which Hungary also participated, took place in 1990–91, and the mathematical and scientific knowledge of students was assessed in two age groups (9 and thirteen-year-olds). Besides studying the attainment differences between the participating countries, the curricula of these countries were analysed and information was collected about the students' family background, classroom environment and their countries' educational system (Lapointe, Askew, & Mead, 1992). Twenty countries participated in the second IAEP study on a voluntary basis (Brasil, Canada, China, England, France, Hungary, Ireland, Israel, Italy, Jordan, Korea, Mozambique, Portugal, Scotland, Slovenia, the Soviet Union, Spain, Switzerland, Taiwan, and the United States).

The assessment framework of the study was developed through a consensus-building process with the cooperation of curriculum and measurement experts from participating countries, similarly to the development of the IEA surveys. After reviewing and evaluating several NAEP assessment frameworks, the experts selected and adapted those that contained appropriate subject specific topics and cognitive processes for all participants. The knowledge components under assessment fall into a content and a cognitive dimension, as in the IEA project. The content categories are similar to those in TIMSS 1995 administered a few years later both in terms of their labels and their relative proportions. The same thematic units are given for the two age groups. In addition to the science disciplines of Life, Matter, Earth and space science, the Nature of science is also included.

The American NAEP continued to be administered on a regular basis after the launch of the IAEP surveys, and their evaluation involves not only an analysis of the results but also a detailed comparison of their theoretical framework and the selection of content areas with current TIMSS and PISA frameworks (see e.g., Neidorf, Binkley, & Stephens, 2006; Nohara, 2001).

The Impact of IEA and NAEP Surveys in Hungary

The results of the first IEA assessment triggered a reform movement in Hungary targeting the contents of science textbooks and curricula in the late 1970s. The changes focused on areas where Hungarian students had displayed a relatively poor performance, which indicated that experiment-based methodology (knowledge acquisition based on observations and experiments) and the integration of the scientific disciplines should be encouraged in science education. A set of detailed subject standards was developed and revisions were made to the contents of science subjects, the methods of analysing the contents and the number of school periods devoted to the realisation of the various didactic tasks (Victor, 1979; 1980; Zátonyi, 1978; 1979; 1980).

The launch of the Hungarian system-level longitudinal assessment programs was influenced by the IEA studies and to some extent modelled on the US monitor (NAEP). Two new elements were incorporated in the Hungarian studies (Báthory, 2003): (1) the knowledge, abilities and skills needed for the acquisition of a school subject, or in the terminology of that time "cultural tool knowledge," was assessed rather than subject content knowledge; (2) student performance was followed over time and trend analyses were carried out. At the launch of the Monitor in 1986 four types of knowledge were assessed: reading comprehension, mathematics as problem-solving, information technology and computer science skills and intelligence.

Tasks assessing science competencies appeared later, in 1995, in the Monitor. This was partly due to financial reasons, but another problem was that it had not been clear how scientific knowledge could be transformed into a competency, a means of attaining other types of knowledge. Since with the exception of the 1997 survey scientific knowledge was assessed together with the IEA TIMSS waves, the approach to measurement was determined by the theoretical framework of the international study. The IEA surveys were not limited to competency assessment but also measured specialised subject knowledge (Vári, 1997). The study with the widest coverage was carried out in 1997, where data were collected form all school grades of the Hungarian public education. All of the other data collection points followed the sampling method of the IEA surveys.

In the context of science, the Hungarian Monitor interpreted cultural tool knowledge as scientific intelligence. The test items were related to situations and problems occurring in everyday life, and measured students' ability to explain the various situations, identify their possible consequences and find solutions to problems that will enable them to attain a more thorough understanding of nature (Szalay, 1999).

The surveys of the Monitor were run on a national representative sample with entire school classes of students included. The comparability of data collected at different times and at different ages was ensured through anchor items. The science test of *Monitor '95* focused on topics in individual science subjects (Physics, Biology and Earth science) – students participating in the international studies also completed a Chemistry section – but also included questions not tied to specific subjects (e.g., questions about environmental/ecological effects and scientific reasoning).

Monitor '97 was administered separately from the large international study and the students' previous performance was used as a reference point. The results of students in Grades 6 and 12 could not be compared to any previous results as no science surveys had been conducted among Grade 6 students before, and the test materials for Grade 12 did not contain a sufficient number of anchor items to allow reliable conclusions to be drawn. One of the most important objectives of Monitor '97 was to reveal the causes behind the gradual decline in the science performance of Hungarian students observed mainly in an international context, but also at a national level. Compared to previous science literacy surveys, Monitor '97 placed a heavier emphasis on test items not tied to any specific subject but assessing the use of scientific methods and reasoning (e.g., designing experiments, issues of environmental protection). Questions related to the topic areas of the scientific disciplines (Living world, Physical world, Earth science) were also included.

The results of Monitor '99, which was run together with TIMSS 1999, (Vári et al., 2000) show a decline in science performance relative to the results of TIMMS 1995: The performance of Hungarian students decreased slightly but significantly. The decline was more prominent for biology and geography, and less prominent for physics.

The Content Dimension of the OECD-PISA Surveys

The OECD PISA framework brought about a major perspectivical and methodological shift in system-level educational assessment. While the IEA studies rely on educational curricula in developing their assessment frameworks and the construct to be measured, the PISA programme selects the skills to be assessed based on an analysis of the needs of society and modern theories of learning. Although some of the content knowledge measured in the PISA surveys may be curricular requirement in some countries, the development of the assessment framework does not rely on school curricula (Olsen, Lie, & Turmo, 2001).

Chapter 2 of this volume discusses the evolution of the concept of scientific literacy and the three dimensions of knowledge assessment used by the PISA framework. Of the three dimensions (declarative or content knowledge, cognitive abilities, and context), the dimension of content and the topics included in past surveys are discussed here in some detail. All PISA surveys adhere to the principle that the knowledge, concepts and relationships under assessment must have relevance to real-life situations and must be appropriate to the developmental level of fifteen-year-olds (OECD, 1999).

The scientific knowledge assessed in the 2000 and 2003 PISA surveys covered thirteen broad subject areas: Structure and properties of matter, Atmospheric change, Chemical and physical changes, Energy transformations, Forces and movement, Form and function, Human biology, Physiological change, Biodiversity, Genetic control, Ecosystems, The Earth and its place in the universe, and Geological change (OECD, 2000, p. 78; OECD, 2003, p. 136).

The content knowledge assessed in the 2006 and 2009 surveys focused on the natural world and science. The questions related to knowledge of science were organised into four categories: Physical systems, Living systems, Earth and space systems, and Technology systems. The Physical systems category, for instance, covered the following topics: Structure of matter, Properties of matter, Chemical changes of matter, Motions and forces, Energy and its transformations and Interactions of energy and matter. The items related to knowledge about science were grouped into two categories: Scientific enquiry and Scientific explanation (OECD, 2006, pp. 32–33; OECD, 2009, pp. 139–140).

The Efficient Transfer and Diagnostic Assessment of Subject Knowledge

Content knowledge plays an important role in the process of learning science and developing scientific literacy. Scientific literacy, however, does not necessarily involve expert knowledge in every field; it can, instead, be attained through an understanding of basic disciplinary concepts and relationships, and an ability to use the basic skills of scientific inquiry, problem-solving and critical thinking. Having a precise idea of what students should know and understand by the end of their public education can have an impact on the teaching process and the evaluation of knowledge.

Curricular Principles Revisited

In 2010 an international expert group of scientists, engineers and science educators reviewed the basic principles appearing in the science curricula and assessment documents of various countries and came to the conclusion that the system of these principles is not supported by sufficiently sound evidence, and it is therefore justified to revise it (Harlen, 2010). The expert group saw the multiple goals of science education as the starting point for the development of curricular principles: „[science education] should aim to develop understanding of a set of big ideas in science which include ideas of science and ideas about science and its role in society; scientific capabilities concerned with gathering and using evidence; scientific attitudes." (Harlen, 2010, p. 8).

The author defines an idea as an abstraction that explains observed relationships or properties. Through science education, students should gradually develop understanding of big ideas about objects, phenomena, materials and relationships in the natural world. These ideas not only provide explanations of observations and answers to questions that arise in everyday life but enable the prediction of previously unobserved phenomena. Science education should also develop big ideas about scientific inquiry, reasoning and methods of working and ideas about the relationship between science, technology, society and the environment.

Ideas of science (Harlen, 2010, pp. 21–23):

(1) All material in the Universe is made of very small particles.
(2) Objects can affect other objects at a distance.
(3) Changing the movement of an object requires a net force to be acting on it.
(4) The total amount of energy in the Universe is always the same but energy can be transformed when things change or are made to happen.
(5) The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate.
(6) The solar system is a very small part of one of millions of galaxies in the Universe.
(7) Organisms are organised on a cellular basis.
(8) Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms.
(9) Genetic information is passed down from one generation of organisms to another.
(10) The diversity of organisms, living and extinct, is the result of evolution

Ideas about science:

(1) Science assumes that for every effect there is one or more causes.
(2) Scientific explanations, theories and models are those that best fit the facts known at a particular time.
(3) The knowledge produced by science is used in some technologies to create products to serve human ends.
(4) Applications of science often have ethical, social, economic and political implications.

The development of big ideas is a long process; it happens through learning at school via the gradual construction of knowledge on the foundations of children's prior understanding of the world. The working group also emphasises that the stages of development described by cognitive psychologists should be taken into consideration, and scientific ideas should be taught through activities appropriate to students' existing knowledge. Being familiar with students' prior knowledge, and making use of their everyday skills and experiences in the classroom are especially important at the initial stages of science education.

Methods of Teaching Concepts and Encouraging Conceptual Change

Knowledge acquisition commonly involves the processing of data, facts and a coherent body of information. At times, students also need to memorise disconnected pieces of information, numerical data, codes and symbols, which can be facilitated by using mnemonic devices (e.g., mnemonic pegs, linguistic code, rhythm). It presents a serious problem, however, if students attempt to rely mainly on memorisation, superficial, meaningless rote learning of definitions and descriptions instead of appropriately organising pieces of knowledge and mastering the emerging connections and relationships. The acquisition of scientific knowledge and understanding of the logic and concepts of scientific disciplines is a complicated task requiring substantial cognitive effort, which can be assisted and monitored in several ways.

The traditional approach to concept teaching distinguishes between an inductive and a deductive method of concept development based on the nature of students' prior knowledge about the subject in question. If the students have sufficient prior knowledge, they can formulate a definition of a given concept by themselves on the basis of examples and counterexamples (inductive method). In several cases, however, students cannot rely on their direct sensory experiences or prior knowledge. In this case they learn the concept from the definition provided by the teacher (deductive method). It is especially important in deductive learning that the teacher should encourage the formation of the correct idea or mental model in as many different ways as possible (e.g., verbal description, expressive teacher demonstration, pictures, diagrams, graphic structure, scale models, multimedia teaching videos, computer simulations, teaching accessories, functional models and student experiments).

The classic method of teaching information characterises classroom activities in four steps (Falus, 2003). (1) Communicating the goals of teaching, mobilising students' prior knowledge, motivation. (2) Introduction of the main principles pointing to the similarities and differences between the subject matter to be acquired and the prior knowledge of the students. (3) The explanation of the subject matter, the presentation of related topics. (4) Checking students' understanding of the subject matter. Although this strategy also emphasises the role of prior knowledge and the establishment of links between old and new knowledge, the results of research on misconception and conceptual change suggest that it could be expanded by the inclusion of new considerations and methods.

The encouragement of the organisation of concepts into a hierarchical structure plays a prominent role in the teaching of concepts. This hierarchical structure should conform to the principles of – in Nagy's (1985) terminology – traversability, diversity and reversibility. The traversability of the conceptual system means that the student should be able to move through the structure in both a horizontal and a vertical direction (i.e., knowing which concepts are on the same level as the reference concept, and which are above or below it). The principle of diversity ensures that conceptual entities are characterised in several different dimensions (e.g., form, behaviour, structure, functioning), and the principle of reversibility refers to the importance of accessing the various levels of abstraction (the concrete and the abstract levels should be linked, it should be possible to move from the manipulative to the symbolic level and back). The teacher can assist the acquisition of an appropriate conceptual structure by presenting the conceptual structure of the subject matter in a graphical form (e.g., tables, tree diagrams, Venn diagrams, flowcharts, spider web diagrams) and encouraging students to write an outline or draw their own diagrams (Nagy, 2005). The development of imagery can be successfully encouraged with the help of computer programmes and simulations. A variety of visualisation techniques have been developed by Kozma (2000), for instance, to assist the representation of chemical symbols and processes.

The research area of knowledge representation and that of the process of conceptual change cross paths at several points. The methods and tools encouraging mental model construction appear to be useful in the process of reorganising knowledge and creating and revising schemas. A number of different types of model (e.g., semantic, causal and system models) can be constructed in connection with scientific topics, problems and everyday situations. The process of building these models, incorporating new information and dealing with anomalous data may encourage the reorganisation of existing models and representations and the revision of the knowledge system (Jonassen, 2008).

A prerequisite to the abandonment of misconceptions or the prevention of their emergence is that students should be aware of their own beliefs and implicit assumptions about the world and compare their theories to the accounts given by their peers or by science. Opportunities to do so are provided by conversations, discussions and teacher or student experiments where students are given explanations for everyday phenomena. The process of shaping a conceptual system and evaluating one's own knowledge requires high cognitive engagement, reflectivity, meta-conceptual awareness and advanced reasoning skills (Vosniadou, 2001; Vosniadou & Ioannides, 1998). It is very important for students to realise that their beliefs are not facts but hypotheses that need to be tested, and that what they believe to be true has restricted validity and may turn out to be false in another system, in a different conceptual framework or at a different level of cognition. Learning strategies that may contribute to the attainment of this goal include problem-based learning (Molnár, 2006), inquiry-based learning (Nagy, 2010; Veres, 2010) and the use of metacognitive strategies and the methods of self-regulating learning in the teaching of content knowledge.

Conceptual changes may be encouraged in several ways. One such method is the use of analogies (Nagy, 2006), examples from the history of science, cognitive conflicts between the naive theories of students and scientific explanations. It is worth devoting time and energy to the discussion of information acquired outside of the classroom. Children often hear vague everyday expressions or over-simplified explanations (e.g., the Sun sets and rises, the food in the refrigerator absorbs the cold) from their family, friends, acquaintances and the media. There are expressions that are used both in everyday life and in scientific discourse (e.g., power, work, energy, matter, bond) but their meanings differ in the two contexts.

All these methods remain ineffective if students are not motivated to learn and understand scientific knowledge and if they do not see how they could make use of it later in life. The first few years of schooling are especially important in developing a positive attitude towards science, since it is these years when scientific concepts can be gradually introduced building on the experiences and natural curiosity of students.

Curiosity and inquiry continue to be essential in maintaining an interest in science in later years, and they can be complemented by encouraging students to raise questions and problems of their own and do research to find solutions.

Diagnostic Evaluation of the Acquisition of Scientific Knowledge

To be able to guide conceptual change, teachers must know what their students think of the discoverability of the world, and of the cognitive processes of knowledge acquisition and knowledge structuring taking place in their own minds. This means that the mapping of students' views, beliefs and prior knowledge and the monitoring of the progress of their knowledge are of crucial importance in the teaching of scientific knowledge. As a method of achieving this, teachers should raise and discuss problems and use concept-mapping, questions or tasks developed on the basis of the results of interviews and misconception research to identify misconceptions related to specific topics. The available results of research on knowledge acquisition provide several guidelines for finding out whether students entertain misconceptions, how well they have understood the subject matter and whether there are any conflicts between their prior knowledge and the scientific information.

Research evidence on the process of conceptual development and the phases of knowledge acquisition is used not only for the development of classroom assessment methods but also for the establishment of learning standards. Researchers attempt to predict the progress of development, identify the milestones and major stages of concept construction and indicate the extent of learning progressions (Corcoran, Mosher, & Rogat, 2009). What this means is that concepts may be incomplete or inaccurate at the beginning of the developmental process and will be revised and reorganised at later stages. This approach calls for not only the reinterpretation of the way standards are set but also a revision of the goals and methods of student assessment. Learning attainment indices are defined that give an indication of students' likely thought processes, the limits of their comprehension and what activities they have the ability to do at various points of their development. At present researchers are working on the development of assessment tools that can identify the stages of learning progressions, show the changes in student performance over time and characterise the development of their reasoning processes between the initial and final stages. The availability of detailed evidence on changes in student knowledge helps to refine teaching methods and to give classroom activities a more purposeful direction.

Summary

This chapter has discussed methodological and curricular issues in science education. We presented the major trends of the past few decades in educational reform efforts. As a starting point, we described research programmes constituting the theoretical foundations of early science instruction and the adjustment of curricular content to fit children's psychological development. These scientific achievements make it possible to find solutions to the problems observed in recent years in relation to the efficiency of science education and student attitudes. We have emphasised that the efficiency of the transfer of scientific knowledge can be substantially increased if the natural process of students' conceptual development is taken into consideration and the conditions of understanding are created.

The disciplinary contents of science instruction have been characterised through a description of the science curricula and educational standards of various countries and the content frameworks of international surveys. Analysing the history of science education, three main approaches can be identified. The discipline-oriented approach sees students' familiarity with the logic, basic topics and methods of individual disciplines and their ability to fit new scientific results into the system of a given scientific field as the primary goals of science instruction. The integrative approach highlights the inter- and multidisciplinary nature of science and argues for various ways and degrees of integrating traditional science subjects. The third approach views science education from the perspective of society and focuses on the application of scientific achievements, especially the exploration of interactions between science and society. While there are several interpretations within these three classes of approach, the Hungarian education system as a whole is characterised by the discipline-oriented view. This view encourages the development of expert knowledge within a specialised field and is beneficial for a relatively small section of students, namely those preparing for a career in science.

In recent years the focus of science education has shifted from the development of expert knowledge to the development of cognitive skills and the emergence of a knowledge system applicable in a broader set of contexts and allowing the interpretation of the relationships between science and society. This does not mean that specialised content knowledge is considered to be unnecessary, since the meaningful acquisition and organisation of scientific knowledge are essential components of the development of both scientific literacy and cognitive skills. At present the main question is what sort of content serves these goals best. In addition to considerations related to the fields of science, the selection of content for science education takes social and psychological considerations into account with increasing emphasis. Specifying fundamental facts related to science and scientific inquiry helps to highlight important content knowledge in curricula, standards and the classroom. At the same time, the research results on child development and the organisation of knowledge and conceptual development allow educators to give greater consideration to the natural process of student development during the course of the teaching and evaluation of student knowledge.

The incorporation of the achievements of research in developmental and cognitive psychology in the past decades is indispensable for the successful teaching of science in the first years of schooling. It is similarly important to take these principles into account in the development of diagnostic assessment methods. These goals should not, however, lessen the significance of the acquisition of disciplinary knowledge reflecting the principles and structure of scientific fields. The development of the intellect cannot succeed without the acquisition of the methods, principles and major achievements of scientific research. The knowledge directly applicable in specific fields cannot be transferred to other fields. Wide-ranging applicability can only be ensured by systematically constructed and well-understood specialised knowledge. These principles are reflected in the educational approach that places the main emphasis on the teaching and thorough learning of big ideas, especially in the first years of formal education. All these considerations, i.e., the importance of the disciplinary organisation of knowledge, should also be taken into account in the development of diagnostic assessment procedures.

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4

Diagnostic Assessment Frameworks for Science: Theoretical Background and Practical Issues

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Introduction

The main function of this chapter is to create a link between the previous three theoretical chapters and the detailed content specifications appearing in the next chapter of this volume. We further provide a characterisation of the genre of frameworks and discuss the considerations justifying our choice of solutions.

Chapter 1 gave an overview of international research findings related to the development of scientific thinking and in general to the role of science in the improving thinking processes, approached mostly from the perspective of developmental psychology. Chapter 2 is similarly based on international research findings, but approaches the issue with the external goals of science education kept in mind. Chapter 3 moved on to the traditions and curricular features of public education in Hungary and a picture of the system emerged to which the diagnostic program would need to be tailored. All this information delineates the first problem to be solved: the achievements of the forefront of scientific research must be adapted to such an extent that they have the greatest educational effect both on individual students and on the public education system as a whole.

The diagnostic assessment system is developed in parallel for three main domains, each of which rests on the same set of principles.[1] The parallel treatment of reading, mathematics and science is justified by several principles of psychology and education as well as by considerations of education organisation. On the one hand, an appropriate level of reading comprehension is essential for learning both mathematics and science and on the other hand, mathematics and science enhance reading skills by offering texts that do not appear among literary styles. The logic of mathematics and that of language can mutually reinforce each other. Science is the best practice field for the application of relationships learnt in mathematics. Drawing attention to and making use of different types of relationship systems is especially important during the first stage of schooling, when students' intellectual development is very fast-paced and exceptionally sensitive to stimulating factors.

The parallel treatment of the three domains has the further advantage that they mutually fertilise one another, the ideas and formal solutions emerging in one can be used in the other two. The development of test questions, uniform measurement scales, data analysis methods and feedback systems also calls for the parallel treatment of the three domains and the sharing of certain principles. This parallel treatment also means, however, that certain compromises must be made: there is a limit to what extent the same principles can be adhered to in all three domains. In the interest of uniformity, the three-dimensional approach is preserved and uniformly applied, but the interpretation of each dimension takes the special features of individual assessment domains into account.

Another benefit of parallel treatment may be a complementarity effect. The three domains are discussed in a total of nine theoretical chapters. We made no effort to create parallel chapter outlines. This made it possible to give in-depth coverage to one issue in one domain and another issue in another domain. In the first chapter of the volume dedicated to the

1 This chapter also contains sections appearing in the corresponding chapters of the other two volumes.

domain of reading, for instance, special emphasis is given to issues in developmental psychology and neuroscience, which also offer important insights for mathematics and to some extent for science education. Certain reasoning skills are discussed in greater detail in the first chapter of the science volume, but the same skills are also important for mathematics education. The second chapters of the volumes focus on the issue of knowledge application and each of them draw general conclusions that equally apply to the other two domains. The third chapters examine practical questions related to the curriculum in their respective domains, but they share a commitment to the historical traditions and current principles of Hungarian public education. At the same time, the proposed choice and structuring of the contents of education also reflect the need to follow progressive international trends and to make use of the achievements of other countries.

In line with the above principles, we regard the nine theoretical chapters in combination as the theoretical foundation of the diagnostic assessment system. The background knowledge analysed in these chapters thus constitutes a common resource for each of the domains, without the need to detail the shared issues separately in the equivalent chapters of the different volumes.

The first section of the present chapter reviews the main factors taken into consideration during the development of the frameworks. First, the tools used for the specification of the goals of education and the contents of assessment are discussed and our solution to the problem of providing a detailed characterisation of the contents of diagnostic measurement is outlined. The next sections show how these principles are used in the development of the science frameworks.

Taxonomies, Standards and Frameworks

The development of frameworks of diagnostic assessment was assisted with a number of different resources. Our work followed an approach undertaking to offer a precise definition of educational targets and of the contents of assessment. First, we discuss various systems used around the world to characterise contents, which we then use as a standard of comparison in describing the method we developed.

Taxonomies

Efforts to define curricular goals in great detail first appeared in the 1950s. This was the time when as a combined result of various processes Bloom and his colleagues developed their taxonomic systems, which made a strong impact on education theoretic objectives for the next few decades. One of the triggers prompting the development of the taxonomies was a general dissatisfaction with the vague characterisation of curricular goals, and the other was the rise of the cybernetic approach to education. There appeared a need for controllability, which required feedback, which in turn presupposed the measurement of both intended targets and actual performance. By comparing targets with actual performance, weaknesses may be identified and interventions may be planned accordingly. During the same period, other processes led to a heavier emphasis on educational assessment and the expansion of testing also created a need for a more precise characterisation of the object of measurement.

Taxonomy is essentially a structured frame providing a system of ordering, organising and classifying a set of objects, in our case, the body of knowledge to be acquired. It is like a chest of drawers with a label on each drawer showing what should be placed in it. A taxonomy can also be interpreted as a data table with the headings indicating what can appear in its various rows and columns. Compared to the previous general characterisations of goals, planning based on such a formalised system constituted a major step forward, and prompted educators responsible for defining specific curricular objectives to think very carefully about what behavior could be expected as a result of learning.

The greatest impact was made by the first taxonomic system, one describing the cognitive domain (Bloom et al., 1956), which opened a new path for curriculum and assessment theory. This taxonomic system characterised expected student behavior in concrete, observable categories. The most obvious novelty was the system of six hierarchically organised frameworks, each of which was designed to apply uniformly to all areas of knowledge. Another significant improvement was the level of description that surpassed by far all previous efforts in detail, precision and specificity. As a further advantage, the same detailed description could be used to plan learning processes and to develop assessment tools. This is the origin of the name *taxonomies of objectives and assessments,* which refers to the two functions.

The Bloom taxonomies exerted a significant direct influence first in the United States, and later on this system provided the foundations for the first international IEA surveys (see also Chapter 2). The empirical surveys, however, did not corroborate every aspect of the hierarchy of knowledge proposed by the taxonomic system. Also, the behaviorist approach to psychology underlying the Bloom taxonomy lost its dominant position in the interpretation of educational processes and was replaced by other paradigms, most importantly by cognitive psychology. The original cognitive taxonomies thus became less and less popular in practice. The corresponding taxonomies for the affective and the psychomotor domains were constructed at a later stage and, although used in several areas, they did not make a wide-ranging impact similar to the cognitive taxonomy.

The taxonomies as organisational principles are ‘blank systems’, i.e. they do not specify content. References to specific contents only serve illustrative purposes in taxonomy handbooks. If, for instance, the six levels of Bloom’s taxonomy – knowledge, comprehension, application, analysis, synthesis and evaluation – are applied to the educational goals in a specific area of chemistry, we need to specify what exactly must be remembered, understood, applied, etc. (see e.g., Kloppfer 1971).

The original taxonomies, their revisions or modernised versions gave rise and still continue to give rise to new systems and handbooks guiding the definition of objectives in a similar spirit (Anderson & Krathwohl, 2001; Marzano & Kendall, 2007). A common feature of these initiatives is that they carry on the tradition Bloom established and continue to treat the operationalisation of objectives and the decomposition of knowledge into empirically measurable basic elements as central issues. The methods emerging during the course of taxonomy development later became important methodological resources in the development of educational standards.

Standards in Education

The development of standards in education gained impetus in the 1990s. This process was especially spectacular in the English-speaking world, where previously there had been no normative documents regulating teaching content in public education. In some countries, for instance, – with some exaggeration – every school taught whatever was locally decided upon. Under these conditions, education policy had a very restricted margin of movement and there was little opportunity to improve the performance of the education system. This situation then gave rise to various processes leading to a centrally defined set of educational goals at some level (state or national).

Standards essentially represent standardised educational targets. In contrast with taxonomies – as systems, – standards always refer to specific education content. They are developed by specialist, professional teams, working groups composed of experts in a given field, and depending on the properties of the various fields, several methodological solutions may be used.

Although the development of standards takes the latest theoretical constructs and scientific achievements into account, there may be substantial differences between the science standards of different countries (see e.g., Waddington, Nentwig & Schanze, 2007). Standards are usually descriptive and define what a student should know in a given subject on completion of a given grade of school.

As the standards were developed, they were also put into practice both in assessment and in teaching processes, similarly to the earlier taxonomic systems. A series of handbooks were published discussing in great detail the methods of standard development and their applications. There are differences in emphasis, however, compared to the taxonomies. Standards have a direct effect first of all on the contents of education (see e.g., Ainsworth, 2003; Marzano & Haystead, 2008), and the question of assessment based on them is of secondary importance (e.g., O'Neill & Stansbury, 2000; Ainsworth & Viegut, 2006). Standards-based education essentially means that there *are* certain carefully specified, standardised education targets that students of a given age can be expected to attain.

The concept of standards and standards-based education is not entirely new to professionals working in the Hungarian or other strongly centralised education systems. In Hungary, before the 1990s, a single central curriculum specified all education content and a single textbook was published based on this curriculum. Every primary school student studied the same contents and in theory everyone had to achieve the same set of targets. The standardised subject curricula were polished through several decades of practical professional experience in some areas (mathematics, science), while other areas remained subject to the whims of political and ideological agenda. While the processes taking off in the 1990s were greatly influenced by the Anglo-American standards-based model, curriculum regulation could not avoid the pendulum effect and has swung to the other extreme: the current Hungarian National Curriculum contains only a minimum of central specifications. This process took a course contrary to what was taking place in other countries. As a comparison, it is worth noting that the volume discussing the American mathematics standards (National Council of Teachers of Mathematics, 2000) is alone longer than the entire first version of the Hungarian National Curriculum published in 1995. Since then the National Curriculum has become even shorter.

The appearance of standards and standards-based education is not, however, a simple matter of standardisation or centralisation but also introduces a professional and scientifically based method of organising education content. Standards constitute a new approach, which has become dominant even in countries that also had centrally developed curricula before. In Germany, for instance, where education content is already strongly regulated at the level of federal states, new research efforts have been initiated to develop new-style standards (Klieme et al. 2003). The most important defining feature of standards is that they are scientifically based. The development of standards and standards-based education has launched extensive research and development activities throughout the world.

Both the theoretical foundations of standards-based education and the contents and structure of individual specific standards were an important source of information in the development of frameworks for diagnostic assessments. The decision not to impose a uniform structural solution on the content specifications in reading, mathematics and science but, instead, respect the special features of the different content and assessment domains also reflects the traditions of learning standard development.

The frameworks developed here, however, differ from standards in that they do not define requirements or expectations. They share other features, however: the criteria of detailed, explicit and precise description and a strong scientific basis.

Frameworks

To mirror international practice, we use the term *frameworks* for the detailed specifications we have developed. The frameworks of assessments are similar to standards in that they contain a detailed, structured description of knowledge. They differ from standards, however, in that standards approach education from the perspective of outcomes. In contrast to traditional curricula, frameworks do not specify what should be taught or learnt. They also do not set attainable targets although they do convey implicitly what knowledge could or should be possessed at the highest possible level of achievement.

The most widely known examples of frameworks are the ones developed for international surveys. Self-evidently, in the case of assessment programs covering several countries, standards make little sense. These frameworks therefore characterise the knowledge that can be reasonably assessed. When defining contents, a number of different considerations may be observed. In the first waves of the IEA survey, for instance, the starting points of assessment contents were the curricula of participating countries, i.e., what was usually taught in a given domain.

The frameworks of the PISA surveys cover the three major domains of assessment and for each of these, characterise the applicable knowledge that fifteen year-old youths living in our modern society need to possess. In the development of these frameworks a dominant role is played by the typical contexts of application, and the focus is of course on the application of the knowledge of the given disciplines and school subjects.

A third approach to framework development is rooted in scientific research concerned with learning and knowledge, namely, in the achievements of developmental and cognitive psychology. These considerations also dominate in cross-curricular domains related to more than one (or just a few) school subjects. One example for this type of assessment is the fourth domain of the 2000 wave of the PISA survey, which focused on learning strategies and self-regulated learning. The frameworks of this domain were essentially shaped by psychological evidence provided by learning research (Artelt, Baumert, Julius-Mc-Elvany, & Peschar, 2003). The insights of psychology also help characterise learner attitudes, which have been an object of assessment in almost every international survey, and played an especially important role in the PISA science survey of 2006

(OECD, 2006). A further aspect of knowledge acquisition contributed by psychological research is the structure of problem-solving processes, which was a special domain of assessment in PISA 2003 (OECD, 2004), and the latest results of cognitive research provide the background for the assessment of dynamic problem-solving skills planned for PISA 2012.

The frameworks developed for diagnostic assessments (see Chapter 5) have drawn from the experiences of the frameworks of international surveys. They are similar to the PISA frameworks (e.g., OECD, 2006, 2009) in that they create the foundations for the assessment of the three major measurement domains of reading, mathematics and science. They differ, however, in that while PISA focuses on a single generation of students – 15 year olds – providing a cross-sectional view of student knowledge, our frameworks cover six school grades, assess younger students and place special emphasis on the issue of student progress over time.

Each set of the PISA frameworks is developed for a specific assessment cycle and although there is considerable overlap between individual assessment cycles, the frameworks are renewed for each. The PISA frameworks cover the entire assessment process from the defining of the assessment domains through to the characterisation of the organising principles of the domain, the specification of reporting scales and the interpretation of results. The frameworks we have developed cover selected sections of the assessment process: a definition of the assessment domains, a description of the organising principles and a detailed specification of contents. While the major dimensions of assessment and the contents of measurement scales are defined, performance scale levels and quantitative issues related to scales are not discussed. Given the longitudinal component of student development, the construction of scales requires further theoretical research and access to the empirical data.

Multidimensional Organisation of Assessment Contents

The dominant force shaping the educational innovations of the past decade has been the integrative approach. The competencies appearing in the focus of attention are themselves complex units of distinct knowledge components (and, according to some interpretations, also of affective components). Competency-based education, the project method, content-embedded skill development, content-integrated language teaching and various other innovative teaching and learning methods realise several different goals at the same time. The knowledge acquired through such integrative methods is presumably more readily transferable and can be applied in a broader range of contexts. Similar principles are likely to underlie summative outcome evaluations, and both the PISA surveys and the Hungarian competency surveys embrace this approach.

A different assessment approach is required, however, when we wish to forestall problems in learning and identify delays and deficiencies endangering future success. In order to be able to use assessment results as a tool in devising the necessary interventions, the tests we administer should provide more than global indicators of student knowledge. We need to find out more than just whether a student can solve a complex task. We need to discover the causes of any failures, whether the problem lies in deficiencies in the student's knowledge of basic concepts or in inadequacies in his or her reasoning skills, which are needed to organise knowledge into logical and coherent causal structures.

Since diagnostic assessment requires an enhanced characterisation of student knowledge, we adopt an analytic approach as opposed to the integrative approach dominating teaching activities. An assessment program intended to aid learning must, however, stay in tune with actual processes in education. In line with these criteria a technology of diagnostic and formative assessments is being developed drawing from the experiences of summative evaluations but also contributing several new elements of assessment methodology (Black, Harrison, Lee, Marshall, & Wiliam, 2003; Leighton & Gierl, 2007).

The development of frameworks for diagnostic assessments can benefit a great deal from the experiences of previous work carried out in similar areas, especially from the assessment methods used with young children (Snow & Van Hemel, 2008) and the formative techniques developed for the initial stage of schooling (Clarke, 2001). For our purposes, the most important of these experiences is the need for a multifaceted, analytic approach and a special emphasis on psychological and developmental principles. Previous formative and diagnostic systems, however, relied on paper-based testing, which strongly constrained their possibilities. We replace this method by online computer-based testing, which allows more frequent and more detailed measurements. The frameworks must be accordingly tailored to this enhanced method of assessment.

The Aspects of the Organisation of the Content to be Assessed

The contents of assessments can be organised in terms of three major perspectives. This three-perspective arrangement creates a three-dimensional structure, which is schematised in Figure 4.1. In expounding the contents of measurements, however, the building blocks of this three-dimensional structure need to be arranged in a linear fashion. The components of the structure may be listed in various different ways depending on our first, second and third choice of dimension along which we wish to dissect it. In what follows, the structure is peeled open in the way best suited to the purposes of diagnostic assessment.

Our first perspective, the objectives of education, is a multidimensional system itself that encompasses the three major dimensions of our analysis: the psychological (cognitive), social (application) and disciplinary (school subject) objectives. It is these three dimensions for which development scales are constructed in each assessment domain (reading, mathematics and science) (see the next section for details).

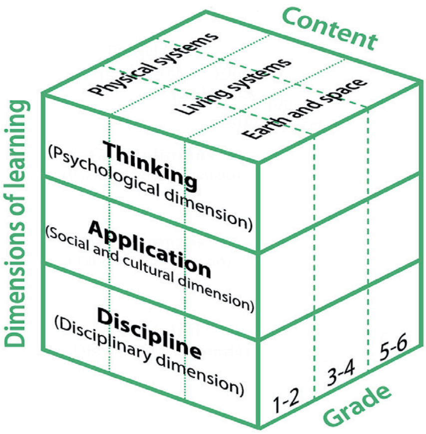

Figure 4.1
The multidimensional organisation of the content of assessments

Our second perspective is development. In this dimension, the six grades of school are divided into three blocks of two years each: Grades 1–2, 3–4 and 5–6. Since the period spanning the six grades is treated as a continuous development process, the above grouping is simply a technical solution to the problem of content disposition. In the absence of empirical evidence, the assignment of contents to different ages (grades) can in any case be no more than an approximation.

Finally, our third perspective is the question of contents available to a given domain of assessment. The content blocks thus broken up constitute the units of the detailed frameworks. With the various possible combinations of the different perspectives, increasing the number of values in any given dimension may easily lead to a combinatorial explosion. In order to avoid that, the number of assessment contents must be determined with caution. The combination of the three learning factors, three age groups and three main content categories of science creates a total of 27 blocks. Identifying further subcategories would substantially increase this figure.

Scales of Diagnostic Assessments, Psychological, Application and Disciplinary Dimensions

Drawing on our experiences of previous empirical studies, the model we have developed is structured along three dimensions corresponding to the three main objectives of education. These objectives have accompanied the history of education and also correspond to the main targets of modern educational performance assessment (Csapó, 2004, 2006, 2010).

The cultivation of the intellect and the development of thinking are objectives that refer to personal attributes rather than invoke external contents. In modern terminology this may be called a *psychological* dimension. As was mentioned in the previous section, this dimension also appeared in the PISA surveys. We have seen a number of assessment domains that interpreted the contents of measurement in terms of psychological evidence. In the case of science, the function of this dimension is to reveal whether science education improves thinking processes, general cognitive abilities or more narrowly defined scientific reasoning to the expected extent.

Another long-standing objective is that schooling should offer knowledge that can be used and applied in non-school contexts. This consideration is termed the *social* dimension and refers to the usability and applicability of knowledge. The concept of knowledge application is related to the notion of transfer of learning, which is defined as the application of knowledge acquired in a given context to a different context. There are degrees of transfer defined by the transfer distance.

The third major objective is that the school should ensure that students acquire the important elements of the knowledge accumulated by science and the arts. This goal is attained when students approach learning observing the principles and values of the given discipline or field of science. This is the *disciplinary* dimension. In recent years a number of educational initiatives have been launched in an effort to counterbalance the previous, one-sided disciplinary approach. Competency-based education and performance assessment focusing on the issue of application have somewhat overshadowed disciplinary considerations. However, for a course of studies to constitute – in terms of a given discipline of science – a coherent and consistent system, which can be reasonably understood, it is necessary to acquire those elements of knowledge that do not directly contribute to the development of thinking or application processes but are indispensable for the understanding of the essence of the discipline. That is, students must be familiar with the evidence supporting the validity of scientific claims and learn the precise definitions ensuring the logical connectedness of concepts in order to possess a system of knowledge that remains coherent in terms of the given scientific discipline.

The three-dimensional model ensures that the same contents (possibly with minor shifts in emphasis) can be used for test task specifications in all three dimensions. Let us illustrate this feature through the skill of organisation. At an elementary level, the operations subsumed under organisation skills, e.g., ordering, classification and grouping, appear during the childhood years. The objects in the world are grouped into categories and conceptual categories cannot be constructed without recognising similarities and differences between these objects or without deciding what attributes to use as a basis for categorisation. The various aspects of organisation skills are improved by classroom exercises and also by the structured presentation of scientific knowledge. The developmental level of organisation skills may be measured with the help of reasoning tasks based on simple content (e.g., classification of everyday objects, grouping of items of clothing according to the season of the year in which they are worn). The task of application may be embedded in an everyday situation such as the grouping of food items to plan a daily and weekly diet according to various criteria (e.g., composition and nutritional values). Finally, we can test whether students have acquired the principles used in biology to classify life forms, the basis of categorisation, the main groups of life forms, the names of these groups and ways of visualising the relationships between the groups and the hierarchy of life (e.g., tree diagrams or Venn diagrams). The last of these is a knowledge component that cannot be developed through exercises stimulating cognitive development but requires specific disciplinary knowledge.

The learning of science is closely connected to general intellectual development. Formal operations and thinking play a dominant role in every area of science and in several areas the applicability of knowledge also has a prominent place. For this reason, there may not be a sharp boundary between the three dimensions in all cases. Whether a certain task belongs to the dimension of thinking, application or disciplinary knowledge depends on the degree of association between the content it measures and disciplinary knowledge, the course syllabus or the context of classroom activities.

The Psychological Dimension of the Assessment in Science

The development of thinking skills and the assessment of their level of advancement as proposed in the detailed frameworks are discussed in the first section of the next chapter, where – in addition to the system of competencies shared with the domain of mathematics – examples are also provided for the assessment of domain-specific elements of scientific inquiry and research. The theoretical framework underlying the examples is presented in Chapter 1 of the volume, where the system of general thinking abilities and various issues in development and the fostering of development are discussed and the relationship between everyday thinking processes, general scientific thinking and the specific reasoning processes of the natural sciences is analysed.

Thinking in Sciences

Scientific thinking is often regarded as a specific mode of thinking. It is used as a cover term for all mental processes used when reasoning about some content of science (e.g., force in physics, solutions in chemistry or plants in biology), or when engaged in a typical scientific activity (e.g., designing and performing experiments) (Dumbar & Fugelsang, 2005). Scientific thinking encourages the development of general thinking skills and is at the same time a prerequisite to the successful acquisition of scientific disciplinary knowledge.

Scientific thinking cannot be reduced to familiarity with the methods of scientific discovery and their application. It also involves several general-purpose cognitive abilities that people apply in non-scientific domains such as induction, deduction, analogy, causal reasoning and problem-solving. Specific components of scientific thinking are linked with specific steps in scientific investigation (e.g., the formulation of questions, the recognition and clear definition of problems; the collection and evaluation of relevant data; the drawing of conclusions, an objective evaluation of results; and the communication of results). They involve the analysis of scientific information (e.g., the comprehension of scientific texts, evaluation of experiments and establishing connections between theories and facts). Further components of scientific thinking include knowledge related to the workings of science and to the evaluation of its impact (e.g., the explanation for the constant evolution of scientific knowledge; the recognition of the close relationship between the physical, the biological and the social world; the recognition of the utility and dangers of scientific achievements; evidence-based reasoning and decision-making), which leads to the dimension of knowledge application.

Development of Scientific Thinking

The intellectual development of children cannot be separated from the evolution of other components of their personality. Students' interests vary with their age: children of different ages think and act differently and have a different relationship to reality. Since there may be substantial individual variation in the pace of cognitive development, the different age-defined stages can have no rigid boundaries. For our frameworks, Grades 1 to 6 of schooling are treated as a single developmental process and, in the absence of empirical evidence, the developmental stages of thinking skills are not linked to the three age groups. However, for the interpretation of the development of thinking and for the analysis of thinking operations, we rely on the psychological attributes known from developmental psychology and make a distinction mainly between Grades 1–4 and Grades 5–6.

In terms of Piaget's stages of cognitive development, the age group covered by Grades 1–6 is essentially characterised by Concrete Operations but signs of the next stage, Formal Operations, may also appear in Grades 5–6. Students in Grades 1–4 are characterised by concrete operations related to their experiences: they can handle a limited number of variables; they can recognise and describe the relationship between the variables but cannot provide an explanation for it. In the Formal Operational stage children can handle problems involving several variables; they can predict and explain events. When characterizing an ecological system, for instance, a student in the Concrete Operational stage will be able to recognise and describe a simple food chain and identify the relationship between the members of the food chain. However, to be able to understand the dynamic balance of the ecosystem as a multivariate system and to understand that a change in the system may bring about further changes upsetting this balance, a higher level of thinking is needed (Adey, Shayer, & Yates, 1995).

The development of scientific thinking is closely related to the level of mathematical skills and to their applicability. The process of scientific inquiry and the operation of scientific research skills require, for instance, elementary counting skills, an ability to use the concept of proportionality, calculate percentages, convert units of measurement, display data, create and interpret graphs, and think in terms of probabilities and correlations.

The operations involved in scientific thinking may be developed from the start of formal education. During this period, a special role is played by direct experience and the observation of objects and phenomena but thinking operations may also be encouraged without performing experiments (e.g., by designing experiments and analysing the results of observations and experiments). As students get older and move forward in their school, the curriculum and the textbooks expect them to learn and apply increasingly difficult scientific methods with a growing number of content areas, while displaying an increasing level of independence (Nagy, 2006a, 2008, 2009).

Several methodological publications have pointed out that young children should be involved in doing science ('sciencing') rather than be taught ready-made scientific facts. The action-oriented and the inquiry-based approaches have also been adopted in science education for young children; with the help of activities and tasks, the children are encouraged to raise questions, search for answers, design experiments and collect data. The results of research on this method suggest, however, that only a few children can acquire the system of scientific knowledge based on simple discovery-based learning. A combination of directed discovery and explicit instruction is a more efficient method.

Chapter 5 discusses how to take into account in the assessment of scientific thinking the psychological attributes characterizing the stages of development of children in Grades 1–4 and 5–6 and the order of appearance of cognitive operations following from them. The operation of general thinking processes is characterised with reference to contents selected from the three science content areas. The development of the detailed content framework made use of the experiences of previous assessment programs in Hungary: with respect to general thinking abilities, the results of studies on inductive (Csapó, 2002), deductive (Vidákovich, 2002), analogical (Nagy, 2006b), combinatorial (Csapó, 1998) and correlational (Bán, 2002) reasoning and organisation skills (Nagy, 1990). The assessment of domain-specific processes is illustrated with examples from the areas of scientific inquiry, problem-solving, text comprehension, evidence analysis and decision-making.

The Application Dimension in the Frameworks

In the three-dimensional model of the contents of diagnostic assessments (Figure 4.1), application is the dimension reflecting social expectations related to learning, and focuses on the social utility of knowledge, its applicability to different contexts, the development of transfer of learning and the ability to create connections between science, technology, society and the environment. The social dimension carries approximately as much weight in the detailed frameworks as do the thinking and the disciplinary dimensions. It describes the standards along which it can be assessed whether at a given stage of development students possess scientific knowledge that can be applied in a way useful to their immediate or wider environment.

The theoretical foundations of the dimension of application are provided by the concept of scientific literacy representing the goals and principles of science education. Scientific literacy has several different definitions. While there are differences in emphasis, all of the interpretations invoke essentially the same social expectation. They construct a theoretical framework of applicable knowledge underlying individual decisions and supporting the interpretation and resolution of day-to-day problems.

Applicable Knowledge

Applicable knowledge may be defined as a complex system composed of content knowledge (factual knowledge) and operations (thinking skills) that remains functional in different contexts. Psychological studies (e.g., Butterworth, 1993; Clancey, 1992; Schneider, Healy, Ericsson, & Bourne, 1995; Tulving, 1979) reveal that learning is situational and the activation and application of knowledge are dependent on the relationship between the context of learning and the context of application. That is, application is not an automatic process; students must learn to transfer both contents and operations. During transfer, the similarities and differences between the two tasks or situations must be identified. The distance between the familiar and the novel task may be unequal in terms of contents versus operations. In addition to transfer distance, several attributes and forms of transfer are discussed in the literature (Molnár, 2006). The current detailed frameworks use the concepts of near and far transfer. Near transfer refers to cases where there is a high degree of similarity between the context of learning and the context of application. For instance, the knowledge acquired in the context of a given topic in a school subject may be applied in the context of a different topic of the same school subject or in a different school subject. Far transfer refers to an instance of application where there are substantial differences between the learning and the application situations, such as the application of school knowledge to complete tasks involving everyday situations and real-life problems (Figure 4.2). Transfer of learning and the application of knowledge are greatly influenced by the attributes of the task and the situation or context appearing in the task. For this reason, the context must be described before applicable knowledge can be evaluated.

The Context of Application

The interpretation of context varies considerably between the different disciplines of science (Butterworth, 1993; Goldman, 1995; Grondin, 2002; Roazzi & Bryant, 1993). For the purposes of the detailed frameworks, context is defined as the totality of objects (people, things and events), their properties and interrelationships, i.e., all the information characterising a situation that activates the relevant knowledge and determines the choice of solution to the task problem.

In the international standards and in the theoretical frameworks of the various surveys, context usually appears in the form of pairs of contrasting modifiers, such as 'familiar versus unfamiliar/new;' 'in the classroom *versus* outside the classroom;' or 'scientific/academic versus real-life/realistic.' The first program to provide a relatively detailed characterisation of context was the PISA survey (*OECD,* 2006). Our detailed frameworks essentially adopt the PISA system, where one test component focuses on the context (personal/social/global) and the other component focuses on the scientific contents and problems having social relevance (e.g., health, natural resources, risks) that are assessed in the various contexts. While these components are preserved in our frameworks, the program is extended to include the assessment of the application of knowledge not only in everyday situations but also in school contexts. Three types of school (classroom) context are distinguished: (1) a different topic within the same school subject, (2) a different science subject and (3) a non-science subject (see Figure 4.2). Non-school contexts cover everyday, real-life situations, which are grouped according to the PISA system into personal, social and global settings.

<table>
<tr><td rowspan="3">School</td><td colspan="2">Different topic in the same school subject</td></tr>
<tr><td colspan="2">Different science subject</td></tr>
<tr><td colspan="2">Non-science subject</td></tr>
<tr><td rowspan="3">Real-life</td><td>Authentic</td><td>Personal (self, family, peer groups)</td></tr>
<tr><td rowspan="2">Non-authentic</td><td>Social (community)</td></tr>
<tr><td>Global (life in the world)</td></tr>
</table>

Figure 4.2
The contexts of knowledge application

Real-life situations refer to phenomena, events, questions and problems that students of a given age are expected to be able to interpret and handle for various reasons, e.g., because they are elements of scientific literacy. Since for younger students (Grades 1 to 6), personal experiences play an important role both in learning and in application, and it is primarily the handling of problems in their immediate environment that constitutes relevant knowledge, real-life tasks are grouped into two categories depending on whether students may reasonably have a concrete experience of the situation represented by the task. A task may thus be classified as authentic or as non-authentic. The contexts of authentic tasks are related to situations taken from students' lives (e.g., travelling or sport) involving mostly their personal or occasionally their social environments: issues concerning their own selves, their families, their peer groups or their wider environment. Non-authentic tasks refer to day-to-day problems involving links between science, technology and society that are not directly relevant to children of the given age (e.g., global warming, alternative sources of energy). For Grades 1–6, the majority of social problems and the set of global issues, i.e., issues impacting on the human race in general, are non-authentic.

The Disciplinary Dimension of the Frameworks

Within the content dimension, science contents are organised in terms of two sets of factors: interdisciplinary and disciplinary considerations. With respect to interdisciplinary considerations, we place special emphasis – in agreement with the discussion of the disciplinary dimension in Chapter 3 – on the development of basic concepts, principles and relationship systems connecting individual disciplines. These constitute the foundations of scientific literacy and can be shaped and expanded not only in Grades 1–6 but throughout the period of science education. The science standards of other countries include several examples of specifying basic concepts and principles, and the Hungarian National Curriculum undertakes to follow this practice. The system we propose includes two basic concepts, matter and energy, and the relationships refer to the relationship between structure and properties, the nature of systems and interactions, the notions of constancy and change, the nature of scientific discovery and the relationship between science, society and technology.

The other approach to science contents follows disciplinary considerations. Based on the four disciplines of science, three content areas have been constructed: Non-Living Systems, Living Systems and Earth and Space Systems. The two disciplines of science concerned with the physical world, materials and their properties and states – chemistry and physics – are not treated separately but are contained within a single content area. Even though in Hungary science education is integrated combining the different disciplines into a single school subject in Grades 1–6 (Environmental Studies or Nature Studies), there are reasons to adopt the above division. The separation of the three content areas allows the various elements of disciplinary knowledge to be monitored in the different age groups, and the method provides an organised system showing the different topics, concepts, facts and relationships appearing within each discipline up to Grade 6. Another advantage of distinguishing these three content areas is that the system can be applied to the entire period of science education, including Grades 7–12, where science is taught divided into disciplinary subjects. The three content areas are in line with the system of categorisation used in the PISA surveys. The frameworks for the 2006 and 2009 waves use similar titles for the knowledge areas in the science domain: Physical Systems, Living Systems, and Earth and Space Systems. In addition to these three areas, the PISA surveys also include Technology Systems and topics related to scientific inquiry and scientific explanations (OECD, 2006, pp. 32−33; OECD, 2009, pp. 139−140). In our program, the latter three areas are positioned among interdisciplinary relationship systems.

For each of the three content areas (Physical Systems, Living Systems, Earth and Space), the knowledge components considered to be of special significance from the perspective of the disciplines of science are discussed in the third section of the Chapter 5. Our discussion of the knowledge, skills and competencies that can be taught and assessed in Grades 1–6 takes the research evidence related to students' thought processes and the development of their knowledge system, and notes variations in student knowledge across the different age groups into account. During the first stage of the study of science, students primarily rely on their own experiences, which is an exceptionally useful starting point but in several areas of science, everyday experiences cannot be directly linked to scientific knowledge; the path leading to understanding of science concepts stretches longer than that. Wherever possible, the relevant stages of conceptual development, their typical manifestations and diagnostic features are described. The description of knowledge development is illustrated with sample tasks that can be used in diagnostic assessments. As the disciplinary dimension takes the standpoint of science disciplines, the tasks appearing here assess the level of acquisition of science content knowledge in contexts familiar from classroom activities.

Physical Systems

This content area encompasses knowledge related to non-living systems in nature. Although the Hungarian National Curriculum places heavy emphasis on knowledge related to the physical world even during the foundational stage of science education, an analysis of the currently recommended framework curricula and the textbooks and practice books currently in circulation reveals that for Grades 1–6, contents providing the foundations of the study of physics and chemistry as science disciplines are considerably underrepresented compared to contents for other science disciplines. We consider the first years of schooling to be an exceptionally important preparatory period with respect to the discovery of the physical world and the acquisition of scientific knowledge and the scientific way of thinking. For this reason, the detailed frameworks – in line with the Hungarian National Curriculum and with curriculum and assessment standards in other countries – encourage the early development of the basic concepts of physics and chemistry, and place more emphasis on knowledge areas preparing the ground for the study of these disciplines (Properties of bodies and matter, Changes of matter, Interactions and Energy) than is currently typical of Hungarian schools.

Children are fascinated by the natural and social environment surrounding them, attempt to find explanations for natural phenomena and are curious to know how the technical tools they encounter every day work. The school plays an important part in helping children to organise the knowledge they have picked up in several different places. If the school fails to fulfill this function, the naive theories constructed by the children can lead to the emergence of misconceptions and to their entrenchment. It is a very important task of education to steer students from the very first years of schooling towards the knowledge and way of thinking that will later enable them to understand the role of science and technology in people's lives. The content framework of non-living systems also points out that the varied activities involved in the study of physics and chemistry develop thinking skills that will come useful in the study of other school subjects and will also be needed for later success in life.

Living Systems

The detailed content framework developed for the knowledge area of living systems describes what knowledge is expected of students in connection with living organisms while also referring to related knowledge in physics, chemistry and physical geography. The contents are fully compatible with the teaching principles defined in the National Curriculum and take into consideration the attributes of different age groups and the objective that the acquisition of the subject matter should help enhance students' cognitive abilities and increase their motivation to learn. The system of expected knowledge contents and the definition of knowledge areas (Criteria of life and the properties of living organisms, Single-celled organisms, Plants, Animals, Fungi, Humans, Populations and Environmental Protection) have been developed keeping the school leaving examination standards in biology in mind, thus allowing the system covering Grades 1–6 to be extended to cover the remaining grades of public education. An important feature of the system is that the detailed content framework emphasises the need to teach the methods of the science of biology (observation and experiments), to highlight the close relationship between biology, technology and society, and to describe concepts and relationships reaching across the various knowledge areas from different viewpoints.

Earth and Space

This content area fulfils a special function in the knowledge of science as it includes knowledge components that are closely related to other fields of knowledge (e.g., mathematics) and, due to their connections with social geography, act as a bridge between natural and social science.

The content framework has been developed with reference to the major logical dimensions of geographical and environmental contents. Geography being a science of space and time, the basic knowledge areas are orientation in space and time, the structures of and events in Earth's spheres (lithosphere, hydrosphere and atmosphere), the properties of regional space at different scales (home environment and Hungary, our planet and the Universe) and issues related to space (the relationship between the natural environment and society, the state of the environment). The content framework describes the contents of geography as environmental science in public education and the basics of the competencies required for the acquisition and application of these contents. The development of the framework relied to some extent on standards in other countries and to a larger extent on the results of Hungarian curriculum theoretical research, current educational documents (the National Curriculum and the school leaving examination standards) and recent trends in geography education theory. An important feature of the framework is that special attention is paid to the step-by-step development of skills and competencies related to the knowledge contents for the different age groups.

Summary and Future Objectives

The detailed frameworks of science are no more than the first step in the lengthy process of developing a diagnostic assessment system. Further work on the theoretical background and the detailed frameworks may be assisted by a number of different sources.

The limited time frame of development excluded the organisation of an external professional debate. Now that the frameworks are published in these volumes in both Hungarian and English, they become accessible to a broader academic and professional audience. The feedback we receive from this audience will be the main source of the first cycle of refinements.

A second, essentially constant source of improvements is the flow of new research evidence that can be incorporated in the system. Some areas develop at an especially rapid rate, such as the study of learning and cognitive development in early childhood. Several research projects are concerned with the analysis and operationalisation of knowledge, skills and competencies. Issues in formative and diagnostic assessment constitute a similarly dynamic research area. The results of these projects can be used to revise the theoretical background and to refine the detailed content specifications.

The most important source of improving the frameworks will be their use in practice. The diagnostic system will be constantly generating data, which may also be used to test and rethink the theoretical frameworks. The system offered here is based on the current state of our knowledge. The organisation of the contents and their assignment to different age groups rely not on facts but on what science views as a hypothesis. The measurement data will provide empirical evidence on *what students know* at a given age. This information and the results of further experiments will be needed to find an answer to the question of *how much further can students progress* if their learning environment is organised more efficiently.

An analysis of the relationships among the various tasks reveals correlations between the scales characterising development. In the short term, we can identify the tasks bearing on the nature of one or another scale and those affecting more than one dimension of assessment. The real benefit of the data, however, lies in the linked data points allowing the longitudinal analysis of the results of successive diagnostic assessments. In the long term, this makes it possible to determine the diagnostic power of the various tasks and to identify the content areas the results of which can predict later student performance.

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5

Detailed Framework for Diagnostic Assessment of Science

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The structure of the detailed framework for science mirrors the structure of the theoretical chapters; it is determined by the perspectives of the diagnostic assessment of science knowledge (learning, school grade and content) (Figure 4.1). The main thread along which the framework is organised is defined by the three dimensions of learning (psychological, applicational and disciplinary). The section emphasising the psychological principles and the development of scientific thinking comes first, thereby underlining the importance of the encouragement of intellectual development and thinking processes, in which the study of science can play a key role. The second section discusses the evaluation criteria of the application of science knowledge. The third section details the disciplinary principles of the assessment of science knowledge, the content elements reflecting the system and logic of science. All three sections include student age as a second basic consideration in assessment. At the same time, the linking of specific content elements and thinking operations to age groups and school grades can only be approximate due to the significant variation among students. The third perspective adopted in each section is the question of content knowledge in science education.

Besides the transmission of disciplinary knowledge, another fundamental goal of science education is the shaping of students' approach to science, the fostering of their ability to identify and understand relationships and principles forming the foundations of scientific literacy and allowing the student to view the living and the non-living environment as a coherent system. The basic concepts, relationships and methods of science are common to every science subject, and are mastered gradually over long years of studying different disciplinary contents. Their description contributes to a more meaningful and purposeful transmission of knowledge of science, helps to establish connections between the different topics of the science curriculum and to generalise concrete experiences and observations. It further provides a basis for the development of learning standards and the diagnostic assessment of knowledge. Based on the Hungarian National Curriculum (2007) and the international literature concerning the goals of science education, the following basic concepts, relationships and topics are highlighted in this chapter.

MATERIALS: Material is a basic concept of science; while the description of the structure, properties, states and changes of material is central to physics and chemistry, several topics of biology and geography also contribute to the enrichment of knowledge on materials. For Grades 1–6, the school curriculum focuses on the differentiation of the various types of materials, the properties of materials, and the characterisation of states of matter. It provides the foundations for later understanding of the categorisation of materials, the states and changes of materials, and for the recognition of several other basic principles (for example that there are different types of material; materials have characteristic structures and properties; the living and the non-living natural environment and the built environment are all made up of materials).

ENERGY: Energy is an abstract concept; at the initial stages of science education it is approached at the level of concrete experiences. Students identify different types of energy (electricity, light), and sources of energy in connection with everyday situations and events. They arrive at an elementary-level interpretation of basic principles related to the concept of energy through examples: energy has several forms and it can be converted into several different forms; energy is required for every change and operation, including the functioning of a living organism; the Sun is the primary source of energy for the Earth.

STRUCTURE AND FUNCTION: The recognition of the relationships between the structure and function of things is an essential component of knowledge of science. The curriculum offers several opportunities to guide even the youngest students towards the recognition of some simple relationships and to abstract away from concrete examples.

SYSTEMS AND INTERACTIONS: Science typically approaches problems in the context of a system. The ability to recognise the connections between different forms and levels of organisation and to understand the regulation and information transfer processes and the interactions between and within the systems and the concept of closed and open systems evolves gradually during the study of science.

STABILITY AND CHANGE: Orientation in time and space, the characterisation of the states and changes of systems and their elements, the understanding of the changes over time of processes within and across systems, and the knowledge of the law of the conservation of matter and energy are fundamental components of the learning of science.

SCIENTIFIC ENQUIRY: Knowledge about science, its operation, the origins of scientific knowledge and the methods of scientific inquiry, together with the skills and abilities required for empirical research, model construction and the testing of the adaptability of knowledge are all parts of scientific literacy. The methods of scientific inquiry with which students are most likely to have experience during the first grades of schooling are observation and experiments. Students also learn some basic procedures, e.g., estimation, measuring, comparison, selecting the aspect of observation, asking questions, formulating hypotheses, designing an experiment, collecting data, evaluating, interpreting and presenting results.

SCIENCE, SOCIETY AND TECHNOLOGY: The recognition, understanding and critical evaluation of the complicated relationship between science, society and technology are essential components of scientific literacy and a prerequisite to becoming a responsible citizen of society. A discussion of the social importance and impact of scientific research, learning about simple technological processes, raising questions and problems related to sustainability, environmental protection and civic responsibility are viable activities even at an elementary level provided that they are matched to the experience, knowledge and interests of the students.

Basic concepts and relationships provide reference points for the classification of scientific content and assist the development of thinking and the emergence of knowledge application skills. The methods of scientific inquiry are discussed in detail in the section on the development of thinking, while the connections between science, society and technology are discussed in the section focusing on the assessment of the application of science knowledge. In each of the three sections, possible methods of developing and assessing individual knowledge elements are illustrated through sample tasks or task ideas embedded in the text. The dimension to which the specific tasks may be linked is indicated by the codes R for reasoning, A for application and D for disciplinary.

The Development and Diagnostic Assessment of Reasoning in Science

Almost any scientific content may be used to develop and assess thinking skills. Initially, content can be presented using manipulative and visual methods, which can give way to formal presentation at later stages. The present section provides guidelines primarily for the diagnosis of the development of thinking skills based on science content adjusted to the range of thinking operations and skills essential for the study of science as described in Chapter 1. Methods of fostering development are also suggested. The fact that thinking skills are discussed in separate sections is not meant to imply that they are independent of each other; the various components interact and rely upon one another. Since they can be classified along different dimensions and based on different criteria there may be some overlap: some operations are assigned to more than one type of skill. For instance, the operation of comparison, the identification of similarities and differences between various properties and relations, involve not only inductive reasoning but also systematising skills.

Conservation

To achieve understanding of the properties of matter it is necessary to be familiar with the principles of the conservation of matter, to be able to identify constant and variable properties under specific conditions and to understand the reversibility of changes. The developmental stage when students progress from the preoperational stage to the stage of concrete operations occurs approximately in Grades 1–2. The preoperational stage is characterised by an unorganised system of operations resulting in cognitive behaviours such as centration (the child focuses only on one thing) and unidirectional thinking. Until the age of about 7, children are unable to control the direction of their reasoning and cannot reverse a process learnt in a given direction. According to the results of Piaget's research, children are ready to recognise the conservation of matter at around the age of 7–8, the conservation of mass at age 9-10, the conservation of volume measured by the water displaced by a submerged object at the age of 10-11, and spatial permanence at around the age of 11. Classic conservation tasks related to the conservation of matter, volume and mass may be used in Grades 1–2 in diagnostic assessments. A simultaneous analysis of two or more properties may be required in Grades 3–4 (Tasks R1 and R2).

Task R1

We pour the milk from the glass into the bowl. Which statement is true?

The event…

changes both the volume and the shape of the milk.
changes only the volume but not the shape of the milk.
changes only the shape but not the volume of the milk.
does not change either the shape or the volume of the milk.

Task R2

We move the marble from a smaller glass into a bigger one. Which statement is true?

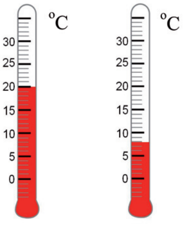
The event…

changes both the volume and the shape of the marble.
changes only the volume but not the shape of the marble.
changes only the shape but not the volume of the marble.
does not change either the shape or the volume of the marble.

The realisation that certain properties change under certain conditions while others do not (Task R3), and that there are reversible processes – where the original material can be recovered – and there are irreversible ones (Task R4) represents a higher level in the understanding of the changes of materials.

Task R3

Kate wondered what the temperature was outside, so she took the thermometer from the room to the balcony. The picture shows the change that occurred after a few minutes. Which property of the thermometer fluid changed?



mass   volume   shape   density

Task R4

Are the following changes reversible? Justify your answer.

We burn the firewood.   We dissolve the sugar in the tea.
We grate the cheese.   We warm up the water.

Systematising Skills

The operations related to sets and relations constitute the mathematical basis of systematising skills. The subject matter of environmental and nature studies is descriptive, and therefore there are several opportunities to characterise the various living organisms, objects and events according to given criteria. The criteria of characterisation may at the same time be the criteria of comparison as well.

The development of systematising skills is rooted in COMPARISON, the identification of the similarities and differences between objects based initially on one and then on more criteria, e.g., comparing a horse with a cow in terms of build and feeding habits. We may ask for comparison without specifying the criteria, letting students choose their own (Task R5). In higher school grades, students are able to relate the various criteria to one another.

Task R5

What do the phenomena illustrated in the pictures have in common and what are the differences?

CLASSIFICATION involves the comparison of an object to a cluster of properties rather than a comparison between two objects. A cluster of properties defines a set. The simplest case of classification is when we have to decide whether a specific object belongs to a given set. For instance: Is the cabbage butterfly an insect? Why? The reverse task is to identify the common properties of objects and label their class, which is a more difficult task (Task R6). Classification is even more complicated when a collection of objects must be classified into two or more groups. At first it is advisable to specify the categories avoiding intersecting sets, and at a later stage students can be asked to label the sets themselves, which may be made easier by pre-specifying an element of one of the sets (Task R7).

Task R6

Look at the pictures below. Give the four pictures a common title that expresses their similarity. Write a few sentences explaining your choice of title.

Task R7

Sort the birds in the pictures into groups based on the example given. Label the groups.

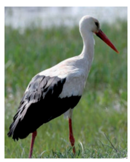
A)

great tit

B)

rook

C)



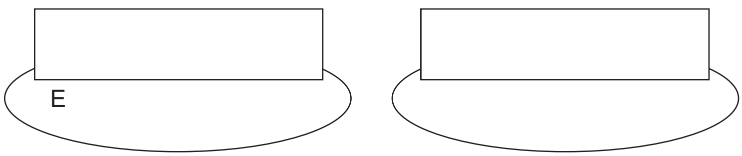
white stork

D)

swallow

E)

house sparrow



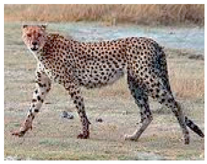
SERIATION involves the arrangement of objects based on the relationship between them, which requires the identification of the ordering criterion. It may be related to chronology, spatial location, quantity or dimension. Seriation is dependent on knowledge of the words expressing relations, e.g., before, after, in front of, behind, below, above, more, less, smaller, larger. Serialisation skills may be developed using several types of content, e.g., putting objects of equal volume in order according to their weight with the help of a density table; setting up feeding relationships, food chains; creating temporal and spatial sequences; ordering the various steps of processes or activities. In Grades 1–2, students may rely on their experiential knowledge when arranging objects by size (Task R8).

In Grades 3–4, we may assess students' knowledge of simple everyday technological sequences and of the chronological order of events (Task R9), while in Grades 5–6 students' understanding of part-whole relationships may be tested (Task R10).

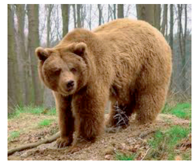
Task R8

Put the animals in order according to their top speed.


hedgehog


cheetah


horse


bear

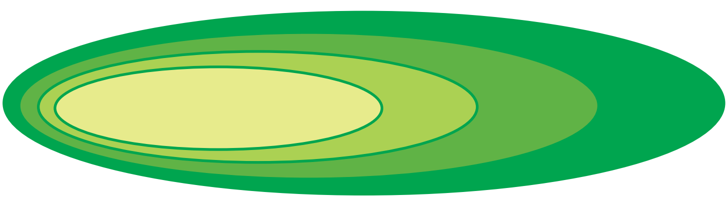
Task R9

How does the pepper get from the garden to the market? Put the events in order.

Task R10

What is part of what? Put the parts of a plant in the appropriate places in the diagram.

carpel plant ovule flower



Systematising operations may be combined with other activities related to the subject matter, as demonstrated by the use of maps in Task R11.

Task R11

Put the four mountains in order according to their height above sea level. The lowest mountain should be the first. Use your book of maps.

………. Kibo   ………. Elbrus   ……… Aconcagua   ……… Etna

Classification and seriation may also be combined. These skills may be assessed even in Grades 1–2 provided that the arrangement of elements can be assisted visually (Task R12).

Task R12

There are four seasons in a year. Every season lasts for three months. Group the months according to the season and put them in chronological order.

December	June	August	February
September	April	November	July
March	October	May	January

Autumn:			
Winter:			
Spring:			
Summer:			

GENERALISATION or SET FORMATION involves the identification of shared properties through the comparison of objects (Task R13) and the creation of a set based on these properties. This operation also underlies classification skills.

Task R13

The properties of some rodents are described below. Find the properties common to these rodents.

ALPINE MARMOT

It is an almost 70 cm long, chunky animal with an approximately 15 cm long tail. It spends 6-7 months in hibernation. The marmot eats mainly the tender shoots of herbaceous plants, leaves, flowers and fruits. There is one pair of incisors in the upper and lower jaws that grow through its entire lifetime. Its female gives birth to up to seven hairless offspring.

MUSKRAT

Its body is 20-27 cm long; its tail is flattened and covered with scales. Its hind feet are webbed. It stays active throughout the winter. It feeds mainly on aquatic vegetation, or occasionally on shells, frogs, fishes and animal carcasses. There is one pair of incisors in the upper and lower jaws that grow through its entire lifetime. It usually gives birth to 5-6 but sometimes to up to 11 offspring.

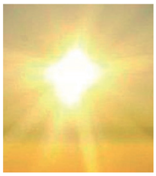
CAPYBARA

Adult capybaras may grow to 130 cm long, their tail is vestigial. Their feet are slightly webbed. They feed mainly on aquatic vegetation, leaves, bark, seeds and grass. There is one pair of incisors in the upper and lower jaws that grow through their entire lifetime. They produce a litter of 2-8 offspring, who follow their mother right after their births.

CATEGORISATION involves the formation of a coherent system of subsets. This operation presupposes the identification of order and seriation. Categorisation may be performed according to one (Task R14) or more criteria, and the criteria may be related to each other, but the application of the latter two types of operation should not be required until Grade 7.

Task R14

Arrange the resources of energy into two groups. State the basis of the arrangement.


the Sun


water


wind


mineral oil

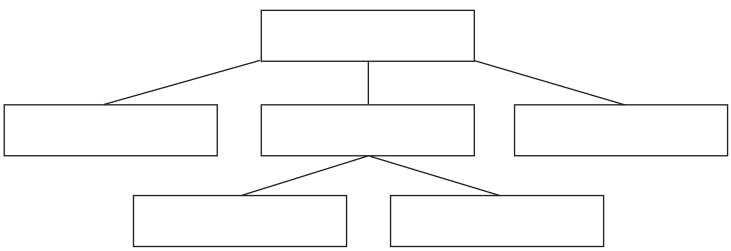

coal

The development of the operation of categorisation may be assisted by visualising the system emerging from the categorisation through tree diagrams, Venn diagrams and charts. These visualisation methods may be used for assessment in the form of completion tasks. Multilevel systems may be created as a result of hierarchical categorisation (Task R15). Hierarchical categorisation is a core operation in science.

Task R15

Organise the arthropods. Complete the chart in agreement with the text.

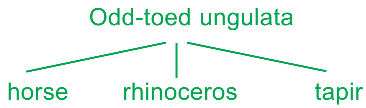
Arthropods are the most populous group in the animal world. They include crustaceans, insects and spiders. Insects with chitinous forewings are called beetles. Butterflies with their spiral tongues are also insects.



DEFINING is the development and verbal description of the rule forming the basis of classification. In Grades 1–2 and 3–4, the development of concept formation skills does not necessarily require scientific definitions; teachers usually provide examples and encourage generalisation by finding common properties, e.g., observation and testing of the properties of gases. Giving definitions may be required in Grades 5–6 provided that the classification criteria and the category of the concept to be defined are pre-specified (Task R16).

Task R16

What kind of animal is the tapir? Complete the sentence based on the information provided by the diagram and on the properties given.



PROPERTIES

They live in tropical forests, they are active at night, they are herbivorous, they have a sensitive and mobile snout.

The tapir is a .... that ....

Combinatorial Reasoning

Combinatorial abilities give rise to new knowledge by considering various possibilities based on existing information. Their functions are to consider and enumerate all the possibilities; to bring unusual connections to surface, e.g., combining different organisational and classification criteria, to differentiate between the actual, the possible and the thinkable; and to construct complete systems. Combinatorial operations include the construction of a Cartesian product, the creation of combinations with or without repetition, the creation of permutations with or without repetition, the creation of all possible permutations and the creation of all possible subsets. The emergence of the operations of combinatorial skills presupposes an ability to generalise the operations of ordering and classification.

Children in Grades 1-6 typically try to solve problems by random guessing. Since they have not yet acquired algorithms allowing a systematic search through possible solutions, whether all solutions are found is a matter of chance. The studies on the development of combinatorial skills suggest that when solving tasks with similar structure presented with either visual or formal content, better performance is to be expected in the case of visual tasks indicating that visualising the situation presented in the task facilitates the finding of the solution. The recognition and consistent application of algorithms appear only later, around the age of 13, with the emergence of formal reasoning.

The fostering and assessment of combinatorial abilities can be started in the first years of schooling. The tasks relate to simple concrete situations; they are illustrated by pictures and contain only a small number of elements, which can all be stored easily in short-term memory. The possible solutions may be presented in a manipulative or picture format, as in Task R17, which may be used to assess the operation of permutation without repetition, where ordered subsets of a given size are selected from a given set.

Task R17

Children brought different kinds of fruit to their environmental study class: chestnuts, walnuts and acorns. They can examine only **two kinds of fruit** during a lesson. Draw **all the possible orders** in which they can examine the collected fruits.

chestnut

walnut

acorn

Task R18 is relevant to the development of environment-conscious behaviour and assesses the operation of permutation where all elements of a given set must be ordered.

Task R18

The students organised waste collection in the village. The students in Grade 2 had to clean **three areas**: the river bank, the area around the waste yard and the playground. **In what order** could they do the work?
List all the possibilities. Use the letters below.

the river bank (**R**) the area around the waste yard (**W**) playground (**P**)

R	W	P						

Task R19 is related to the topic of healthy diet and requires the listing of combinations without repetition.

Task R19

Peter and his family follow a healthy diet, they always have fruit at home. They've bought bananas, oranges, apples and pears this week. Peter packs **two different kinds of fruit** for his mid-morning snack at school. **Which two** can he take with him to school? List all the possibilities. Use the letters below.

banana (**B**) orange (**O**) apple (**A**) pear (**P**)

In addition to the development of reasoning skills, knowledge of the subject matter can also be assessed with tasks where the question element testing one of the components of combinatorial abilities, e.g., combination in Task R20 is supplemented with a question about the subject matter.

Task R20

Tom, Anne, Ben and Carol went to the playground to play on the seesaw. Each child sat on the seesaw **with each of the other children.** List all the possible pairs. Use the letters below.

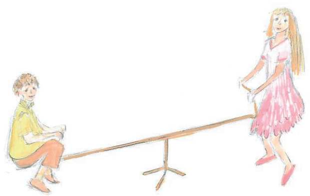
Tom (**T**) Anne (**A**) Ben (**B**) Carol (**C**)

T	A	T	B				

The children have different weights. Which pair could seesaw the most easily?

The weight of the children:

Tom: 56 kg
Anne: 42 kg
Ben: 63 kg
Carol: 57 kg



Combinatorial reasoning is required for designing experiments where the values of the different variables are combined in order to define the experimental conditions. An example is shown in Task R21.

Task R21

We investigate the effect of light and water on the development of plants. Our hypothesis is that plants require light and water to stay alive. We have four pots of wheat. In what kind of environment should we keep the plants to find evidence for the hypothesis? Put a circle around the name of the appropriate environmental conditions below the individual plants.

light − water

light − water

light − water

light − water

Deductive Reasoning

The deductive and inductive modes of reasoning are often interpreted relative to each other. Using the deductive method, we can only state in a different way the information that is already included in the starting claims (the premises) and therefore we cannot acquire fundamentally new knowledge, while inductive reasoning can lead us to new knowledge.

Practice exercises using elements of deductive reasoning, e.g., the operations of classic bivalent logic, deductions and quantifiers) assist the acquisition of the subject matter and scientific terminology, successful everyday communication and the mastery of verification and falsification skills. The results of empirical studies indicate that the development of logical ability in a large part takes place before puberty, therefore fostering these skills is especially important in the first few years of schooling. From among the BINARY OPERATIONS, conjunction (Task R22) and disjunction (Task R23) assist the acquisition of the logical meaning of the connectives 'and' and 'or', which is a precondition for instance to the recognition of the logical connection between conceptual features, and to the proper use of the connectives used to link features in definitions. At later stages, the understanding of the equivalence operation plays an important role in the recognition of the logical relationship between the name of the concept and its feature structure, and in the linguistic encoding of the concept.

Task R22

The sentence below appears on the poster calling for waste paper collection:

SORT THE PAPER AND TIE IT UP.

Put a circle around the letter of the statement where the paper was handled as the poster requested. Cross out those where it wasn't.

A) The paper was sorted but wasn't tied up.
B) The paper wasn't sorted or tied up.
C) The paper was sorted and tied up.
D) The paper wasn't sorted but it was tied up.

Task R23

Four teams (A, B, C and D) investigated the properties of granulated sugar in the school science study group. It is easy both to melt the granulated sugar in a test tube and to dissolve it in water. They read the instructions below on the task card:

Every team should perform exactly one experiment with the granulated sugar:

EITHER MELT OR DISSOLVE THE SUGAR.

Put a circle around the letter of the team that followed the instructions. Cross out those that didn't.

A) The team both dissolved and melted the sugar.
B) The team melted the sugar but did not dissolve it.
C) The team didn't melt the sugar but dissolved it.
D) The team neither melted nor dissolved the sugar.

Among the binary propositional logic operations, the correct interpretation of equivalence and implication (reversible and irreversible statements) is the most difficult. Most students handle these two operations as if they were identical, or they often interpret them as conjunction (as an 'and' operation). These operations can be developed in the first few grades through tasks based on simple situations taken from the students' everyday life, e.g., Task R24.

Task R24

You can hear or read news stories about UV-radiation every day in summer. We know that we should protect ourselves against the harmful UV-rays. Eve wanted to sunbathe one afternoon. Her mother said to her:

YOU CAN ONLY SUNBATHE IF YOU USE SUN-PROTECTION.

Put a circle around the letter of the statement where Eve followed her mother's instruction. Cross out those where she didn't.

A) Eve sunbathed and used sun-protection.
B) Eve sunbathed and didn't use sun-protection.
C) Eve didn't sunbathe but she used sun-protection.
D) Eve neither sunbathed nor used sun-protection.

DEDUCTION involves the interpretation of complex sentences encoding conditional statements – using the linguistic elements of 'if... then' or 'if and only if'. Both the forward implication elimination (Modus Ponens) and the backward implication elimination (Modus Tollens) (Task R25) use the operation of conditional deduction: the first by affirming the antecedent and the second by denying the consequent.

Task R25

Draw a conclusion from the statement. Complete the sentences.

If the air is polluted, tree leaves dry up partially or completely at the beginning of summer. We didn't find any dry spots on the leaves of the horse chestnut tree at the beginning of summer, therefore…

If the temperature drops below zero, the water freezes. The water is not frozen and therefore…

If a vertebrate animal is a bird, then its body is covered with feathers. The body of the squirrel is not covered with feathers and therefore…

A sequence of deductions (Task R26) is based on two conditional statements where the consequent of the first statement is the antecedent of the second statement. An important consideration in the choice of the content of deduction tasks is that the tasks should strengthen the connections between different pieces of knowledge and encourage the discovery of new connections.

Task R26

Continue the sentence.

If the vegetation is destroyed on a hill-slope, then rain will wash the soil away. If the rain washes the soil away, then crops can only be grown in the valley. Therefore, if the vegetation is destroyed on a hill-slope, then...

In quantified reasoning tasks the linguistic phrases 'all' and 'some' and their paraphrases should be used (Task R27).

Task R27

In the next tasks you'll have to decide what may be concluded from the statement in capital letters shown at the beginning of the tasks.

Put a circle around the letters of the conclusions that follow from the statement in capital letters. Cross out those that do not follow from the statement in capital letters.

BIRDS LAY EGGS,...

A) therefore every bird lays eggs.
B) therefore there are birds that lay eggs.
C) therefore there are birds that don't lay eggs.
D) therefore there aren't any birds that lay eggs.
E) therefore there aren't any birds that don't lay eggs.
F) therefore no birds lay eggs.

THE WHALE IS A MAMMAL LIVING IN WATER,...

A) therefore every mammal lives in water.
B) therefore there are mammals that live in water.
C) therefore there are mammals that don't live in water.
D) therefore there aren't any mammals that live in water.
E) therefore there aren't any mammals that don't live in water.
F) therefore no mammals live in water.

Inductive Reasoning

Inductive reasoning involves rule induction and rule formulation. It is usually assessed through word and number analogy tasks, number and letter sequences, and questions involving recoding and exclusion. In order to solve inductive reasoning tasks, students need to identify regularities, continue or complete an incomplete sequence, analogy or matrix by predicting the missing element. Research results indicate that the most intensive development of inductive reasoning skills takes place when students are in Grades 5–7 or 6–8. Using playful tasks, inductive reasoning may be encouraged effectively as early as age 6–7 based on either general or science contents.

The complicated operation of rule induction requires the identification of the similarities and differences between things and events. An 'odd one out' task involves the simultaneous identification of similarities and differences, i.e., the operation of EXCLUSION. In addition to identifying the exception to the rule, these tasks should also ask for an explanation of the decision, which reveals what criteria were used by the students in making their decision. Exclusion tasks where more than one set of criteria can be used to arrive at a correct solution may be given as practice exercises. The difficulty of a task is influenced by the content as well as by students' familiarity with the common properties of the specified concepts.

Task R28, where the basis of similarity (colour) is easily recognised with the help of the pictures, may be used for the diagnostic assessment of inductive reasoning in Grades 1–2.

Task R28

Which is the odd one out? Why?

Pictures assist the identification of similarities and differences in higher grades as well, since they visualise the objects to be compared. Students' answers to Task R29 reveal whether they are familiar with the categories of food. Task R30 requires knowledge of the distinguishing features of animal species.

Task R29

Which is the odd one out? Why?

Task R30

Which is the odd one out? Why?

swan mussel   diadem spider   housefly   river crayfish

Exclusion may be applied to processes, as in Task R31, which assesses the identification of the change of state of water.

Task R31

Which is the odd one out? Justify your answer.

The puddle dries up.
The tree branch becomes frosty.
The river becomes flooded.
The railing becomes covered in hoarfrost.

RECODING involves the application of an operation identified through examples to another given context. An example of this is shown in Task R32.

Task R32

The name of which animal should be written in the blank space?

white stork + grass snake = long-eared owl

domestic horse + house sparrow = May bug

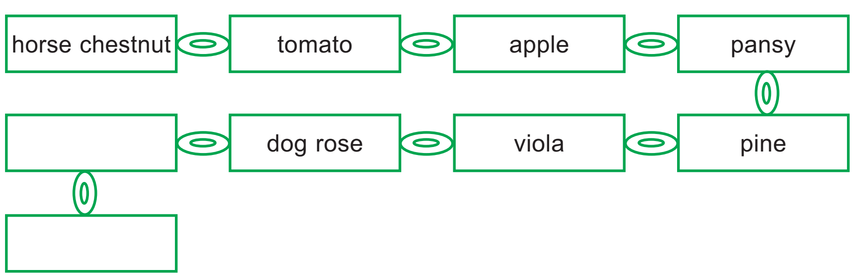
cabbage butterfly + European hare =

horned cattle river crayfish diadem spider housefly

SEQUENCES appear mainly in mathematics, but they may also be practised using examples from science. The generation of sequences requires the identification of the operational rule of the sequence based on some of its elements, and the production of further elements based on the rule. Knowledge of the concept of woody and herbaceous plants is required in Task R33 in order to identify the rule and apply it to other specific species.

Task R33

Add two new elements to the sequence of plant names.



Analogical Reasoning

Analogy is an important component of inductive reasoning. In a wide sense analogical reasoning is interpreted as reasoning based on comparison, and in a narrow sense it is defined as reasoning based on the similarity relation between elements. The similarity relations may apply to labels, shapes, stories, problems or systems. An example of systems is shown in Task R34, where the elementary level concept of ecological system is illustrated by the comparison of a forest with a multilevel family house.

Task R34

A forest is like a multi-level family house. Explain why.

There are several types of relation, such as set membership, part-whole, whole-part, chronological order, cause and effect, effect and cause, contrast, synonymy, function, metamorphosis, place, elements of the same set and functional whole-part. Enabling students to recognise these relationships is a high-priority goal in the teaching of every topic in science. There are several types of tasks used for the development and assessment of analogical reasoning. These include lexical analogies, numerical analogies, geometric and visual analogies, sentence or drawing completion tasks, problem analogies and metaphors. Of the types mentioned above, VERBAL WORD ANALOGIES are the most likely to be used with topic-specific content. Word analogy tasks may be open-ended or multiple choice. In open-ended tasks both items of the source pair and one item of the target pair are given, and the student has to supply the missing item. In Grades 1–2, this may be asked in the form of sentence completion (Task R35) and in later grades we may use the usual format of word analogies (Task R36).

Task R35

Complete the sentence.

A foal is to a horse is like a ….. is to a bear.

Task R36

Replace the question mark by a word based on the relationship between the first two expressions.

lake : still water = plateau : ?

We can distinguish different types of multiple choice tasks depending on the size of the set of choices and on the number of analogy items given. Usually, we offer 3–4 responses to choose from. When selecting the set of responses, care should be taken to include items having the kind of content or logical relation to the item given in the task that provides an opportunity to diagnose typical errors. We may provide both elements of the source pair and one of the elements of the target pair (Task R37), both elements of only the source pair (Task R38), or only one of the elements of the source pair (Task R39). The fewer elements of the analogy are provided, the more difficult the task is.

Task R37

Which of the words would best replace the question mark?

metal : plastic = solid : ?

iron liquid wood state of matter

Task R38

Which pair of terms would best replace the question mark?

mammal : bird = ?

vertebrate : animal
fungus : plant
bird : nest
plant : flower

Task R39

Which expressions and relationships would best replace the question mark?

disease : ?

infection = physician : treatment
health = ice : solid
cold = plum : apple
healing = spring : autumn

Younger children often prefer thematic relationships to other types of relationship. If given the task bird : nest = dog : ? (kennel, bone, other dog, cat), for instance, they tend to choose bone instead of kennel. If they lack the necessary knowledge, the pressure to give an answer may prompt even older children to make their decision based on a thematic relationship.

Word analogy practice tasks provide an opportunity for students to discover the different types of relationship and use them consciously. In addition to revealing the correct response, we may encourage this process by discussing why the remaining choices are incorrect.

MODELS are also based on analogies. Their use is especially important in science since we teach several phenomena that cannot be experienced directly and are difficult for students to form a mental image of. The Earth's rotation around its own axis is a good example. This motion may be demonstrated using a spinning top, a toy well known to children. It is also important, however, to call the students' attention to the differences as well as to the similarities (Task R40).

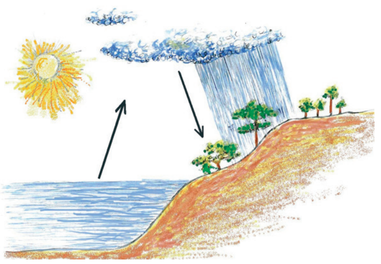
Task R40

What are the similarities and differences between the rotation of the Earth and a spinning top?

Modelling can help to create a link between everyday phenomena known to students and a phenomenon of nature. Task R41 may be used when students have already acquired the elementary level physical knowledge of changes of state; Task R42 presupposes some knowledge of surface shaping and ground erosion. The interpretation of the models assesses whether students are able to draw a parallel between the given phenomena and to identify the elements of the two systems and the steps of the processes.

Task R41

We are making tea. We fill a kettle with water in a kettle and put it on the stove. When the water is boiling, we remove the lid of the kettle. If we are not careful, the steam will burn our hand and drops of water will fall on the stove. Compare the events taking place in the kettle to the natural process depicted by the picture below.



What corresponds to…

the stove?
the air locked in the kettle?
the water in the kettle?
the steam coming out of the kettle?
the water drops on the lid?

Task R42

We are building a sand hill on the sand table. We cover one side with moss, and leave the other side uncovered. We pour water on both sides of the hill. What differences may be experienced between the moss-covered and the sandy surface? Insert the correct mathematical symbols.

The speed of the water flow: on moss-covered surface ☐ on sandy surface

The erosion of the surface: on moss-covered surface ☐ on sandy surface

What kind of environmental protection problem was demonstrated with the model?

Proportional Reasoning

The skills related to proportionality (calculation of ratios, unit conversion, identification of direct and inverse proportionality, proportional division and calculation of percentages) and the teaching of proportional reasoning are parts of the mathematics curriculum, but they also play an extremely important role in science subjects and in everyday life. Proportional reasoning is needed for the identification of the relationships between physical quantities (Task R43).

Task R43

The cubes are made of wood. The volume of one of the cubes is twice as large as that of the other. Which cube has a greater mass? Explain why.

The identification of the relationships between physical quantities, the recognition of direct or inverse proportionality between the data series gained by a series of measurements are not easy tasks even in Grade 6 or later, and several levels may emerge in the reasoning of the students (see e.g., studies by Sándor Zátonyi). The first level, the qualitative level, appears in the comparison of the mass and the volume of objects having the same quality of material but different sizes: the greater the mass, the larger the volume. The second level is the identification of actual proportions (if the mass is twice as great, the volume is twice as great as well). The third level is the generalisation of proportions (the volume will be as many times larger as the mass is greater); the fourth is the labelling of direct proportionality (there is a direct proportionality between mass and volume). For Task R43, explanations of Level 2 should be expected in Grades 5–6.

Although an intensive progression in proportional reasoning is not expected until Grades 7–8, some of its elements can be taught and assessed in Grades 4–6 as well. Proportional reasoning is required to determine the composition of a solution, to understand the relationship between the oxygen-content of the air and the height above the sea level, and to understand the notion of scale in map reading (Task R44).

Task R44

Matthew, Rose and Ben marked cities as travel destinations at a distance of 10 cm from the capital city on maps using different scales. Which city should be best approached by bicycle, car or plane? Choose the appropriate means of transport for each of the children.

Students	Scale on the map	Most practical means of transport
Matthew	1 : 1 500 000	bicycle – car – plane
Rose	1 : 40 000	bicycle – car – plane
Ben	1 : 11 600 000	bicycle – car – plane

In Grades 5–6, simple experiments may be performed based on which students can observe relationships between the data. For instance, they may investigate the relationship between the rate of photosynthesis and light intensity and carbon dioxide concentration.

Probabilistic Reasoning

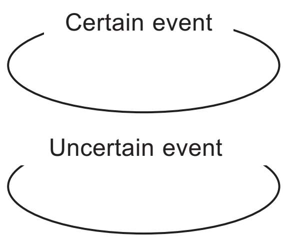
Scientific reasoning and orientation in everyday life equally require the making of probabilistic decisions. There are several phenomena in science that are based on probabilistic relationships. The outcomes of most natural processes influenced by several different factors tend to have a probabilistic nature, e.g., if a seed is planted, it will probably sprout; the co-occurrence of certain meteorological conditions may cause flooding). This fact calls for, and at the same time offers an opportunity for, the introduction of concepts related to probability from the very beginning of science education. To be able to recognise chance occurrence, it needs to be known whether two events are related or are independent of each other. Piaget's observations indicate that young children do not possess these skills. They have to learn to understand the causes of events and to recognise the chance co-occurrence of two events. According to Piaget, children at the preoperational level display a self-contradictory attitude towards coincidence. They believe that under similar conditions, events will always take the same course; if they happen to experience variation, they deny the sameness of the events. At about the age of 7–8, children are no longer surprised by the differences; on the contrary, they take them into account in their predictions. At about the age of 9, they try to find the explanation for the variation. To be able to calculate the probability of occurrence of an event, an appropriate level of development in combinatorial and proportional reasoning is required, hence a significant change in the development of probabilistic reasoning cannot be expected until the age of 11–12.

It is important to teach students to recognise probabilistic relationships since the curriculum is dominated by deterministic relationships, which interferes with the development of probabilistic reasoning. In Grades 1–6, probabilistic reasoning can be assessed through tasks related to the experiences of students (Task R45).

Task R45

There are events that will definitely take place, and there are events that may not. Decide which group these events belong to.

A) The house will collapse in an earthquake.
B) Those who have been born will die.
C) It will snow at Christmas.
D) Spring will follow winter.
E) If a stone is thrown up in the air, it will fall down.

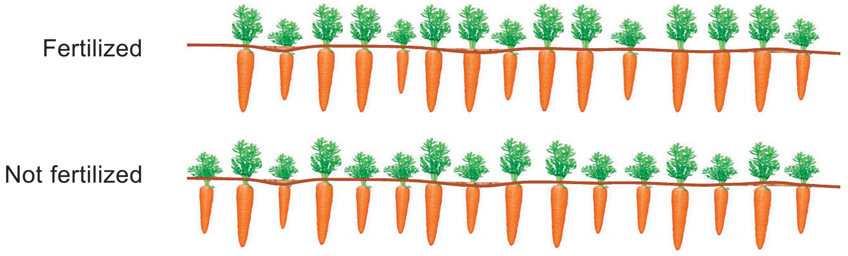


Correlational Reasoning

Correlational reasoning allows the recognition of correlations between events occurring with a certain probability; it is the basis of the recognition of rule-like patterns and relationships between various properties characterising the world. Two basic types may be distinguished: co-occurrence and causal dependence, both of which may be taught using science content. For instance, when students learn about the conditions of life of living organisms, they could discuss what would happen if the living organisms could not access food for a long period of time or if too many trees were cut down on a steep hillside. The recognition of co-occurrence may be assisted by letting students analyze ready-made data series (such as the annual average rainfall in a given area and the quantity of the harvested wheat based on a ten-year period) or data they collected from their classmates (such as weight and height) (Task R46 and 47).

Task R46 (Based on Philip Adey's task)

Did fertilization influence the size of carrots?



Method of soil treatment	Number of carrots by size	
	Small	Large
Fertilized	5	11
Not fertilized	9	7

Task R47

The students in Grade 6 had a medical examination in school. It was found that some of the children in the classes were overweight. The following table shows the data for the three classes. Does being overweight depend on whether the child is a boy or a girl?

Sex	Number of students by weight	
	Overweight	Normal weight
Boy	8	38
Girl	11	43

In their studies of 5–15 year old children, Inhelder and Piaget observed four strategies of correlational reasoning (see the Contingency Table below). Children at the preoperational stage of reasoning consider correlation *a* separately and fail to realise that cases *d* also constitute evidence. The second and third strategies appear at the concrete operational stage. The second strategy involves the comparison of the data in the rows or columns of the bivariate table, e.g., *a-b, a-c*; while the third involves the comparison of the two diagonals of the table. Students start using the fourth strategy only at the formal operational stage, at which level conditional probabilities are compared.

Contingency Table

Variable A	Variable B	
	B1	B2
A1	a	b
A2	c	d

Scientific Experiments

The development of specific elements of scientific thinking (knowledge about the methods of scientific inquiry, the skills and abilities required for empirical investigation, model construction, testing of the adaptability of knowledge) is a long process. An interest in nature emerges early in childhood, which can be exploited by the school even in the first years of science education.

In Grades 1–2, the focus is on generating ideas, raising questions, planning and performing OBSERVATIONS and describing the results of these OBSERVATIONS. At this stage, empirical investigations are restricted to the natural and built environment immediately surrounding the students. Natural phenomena and habitats are observed and the perceptible properties, lives and behaviours of plants and animals and changes in these phenomena are studied based on predetermined observation criteria and questions. Students may describe their experiences orally, by drawing pictures or, as writing skills develop, in writing with some help from the teacher. Perceptual awareness may be developed by providing observation criteria of gradually increasing complexity. In the beginning students should investigate only one property of the objects or events. They can later be given tasks where a single sense organ can be used to observe a number of properties or where objects must be selected based on one or more characteristic features. These tasks may be followed by empirical activities where more than one sense organ is used to observe various properties. The analysis of the information perceived through the different sense organs involves their arrangement and classification, the recognition of spatial relationships, measurement and quantification.

Besides observation, data can also be collected through simple INVESTIGATIONS and MEASUREMENTS. The exploration of some basic, measurable properties of materials and objects provides an opportunity to gain experience with estimation and measurement, and to get to know measuring tools, measurement units and simple testing procedures. At this age, the recording, representation and comparison of the measurement results, the verbalisation and interpretation of the experiences require some assistance from the teacher. It is important that these activities should be simple, easily executable, short and varied. Since children's manual dexterity and coordination skills are not fully developed, they prefer immediate results and loose their interest and their attention slacks when they are asked to perform long experiments.

In diagnostic assessments, we may supply students with data collected through observations, investigations and measurements and ask them to organise, explain and interpret them (Task R48).

Task R48

The students' homework assignment was to ask their parents what body length and weight the students had when they were born. In their environmental study class, the students measured each other's present height and weight in pairs. The table below shows the measurement data of one pair of students. Answer the questions based on the data.

		Peter	Veronica
Height	at birth	51 cm	49 cm
	at present	135 cm	122 cm
Weight	at birth	3kg 18 dkg	3kg 15 dkg
	at present	27kg 23 dkg	21kg 17 dkg

What is common to the changes in Peter's and Veronica's height and weight?
Whose height changed more?
Whose weight changed more?

In Grades 3–4 OBSERVATIONS are performed with increasing autonomy. Students observe the properties of living organisms and changes in these properties, the life and behaviours of various animals, their relationship with their habitat and with other life forms; they collect information about space and the materials in the environment. They compare, categorise and organise the observed material properties.

Students in these grades continue to ESTIMATE and MEASURE the quantities important in everyday life. They observe and measure meteorological elements and perform estimations and measurements of distance, area and duration. They are able to design simple EXPERIMENTS with their teacher's assistance; to observe and interpret processes, events and changes under experimental conditions, e.g., testing of air, water, and soil, testing of the environmental conditions of plants and animals. Tests and experiments help students to distinguish direct experiences from indirect experiences. Students may describe their experiences orally, in writing or by drawing, e.g., description of data, facts; drawing of diagrams, charts or simple models.

In Grades 3–4 students have difficulty distinguishing variables; they think one step at a time without being able to connect these steps to each other. For this reason, activities should be planned keeping this fact in mind and tasks should contain only a small number of variables. The range of thinking operations related to observations, tests and experiments becomes wider at this stage, e.g., students can become increasingly independent in finding a causal relationship between experimental results and everyday experiences; using observation results to make comparisons, identifying similarities and differences, and performing categorisation. At this age students begin to recognise the difference between observation and deduction and between fact and opinion. They are ready to learn about the sources of knowledge not obtainable by direct experience and about ways of making use of the relatively simple ones of these sources. It is important to arouse students' interest in scientific inquiry and the work of scientists even at the initial stages of science education; students should be aware that knowledge of nature is acquired by observation, measurement, testing and experiments.

Diagnostic assessments may include tasks involving the interpretation of experiments and the analysis of data (Tasks R49 and R50). We can ask students to compare data sets, to draw conclusions or to design simple experiments, for instance to prove that air has mass (Task R51).

Task R49

Dan and his friends decided to make a pond in someone's garden. Before starting to build it, they tested the soil. They collected soil samples – from the same depth – from three gardens. They put paper filters into three funnels, and pressed each soil sample in a different funnel. They put the funnels into tall glasses, and poured 100 ml of water onto each sample. The next morning they constructed a table of their experiences.

Answer the questions based on the data.

Property	Soil sample		
	From Dan's garden	From Peter's garden	From Jim's garden
State of soil sample	wet	appr. 1 cm of water on the surface	dry
Amount of water in the glass	30 ml	1-2 drops	100 ml

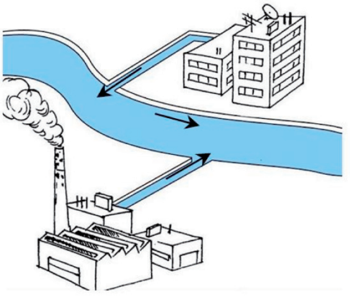
Which soil is unsuitable for making a pond? Justify your answer.
Which soil is the best for making a pond? Justify your answer.

Task R50

We tested water samples and the results are summarised in the table.

Property	Water sample		
	1.	2.	3.
Transparency	very cloudy	completely transparent	transparent
Colour	yellowish brown	colourless	slightly yellowish
Smell	earthy smell	fresh smell	chlorine smell

Where do the water samples come from? Put the number of the samples in the appropriate place in the picture. Justify your answer.



Task R51

Design an experiment to demonstrate that air has mass.
You have sensitive scales and a ball full of air.

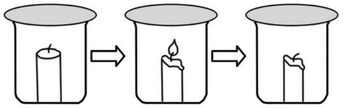
In Grades 5–6, new elements are added to the observations, measurements and experiments learnt at the previous stage. With some help and guidance from their teachers, students are able to define problems related to the environment; to design simple experiments; to make predictions; to carry out experiments; to record and describe their results and experiences in their own words; to compare previous ideas and experiences with the measurement results and look for the causes of the differences; and to evaluate the accuracy of measurements. Students may be asked to record the results in a variety of formats, e.g., description of data and facts; drawing pictures, creating diagrams, maps, tables and surface models and building collections. The experiments may be applied to a variety of topics, e.g., interactions and changes appearing in the environment; comparison and measuring of the qualitative and quantitative properties of different living organisms and events; regular observation and measuring of meteorological elements. Students may also be shown how to construct simple models, e.g., the particles making up matter; the work of rivers, the development of basic surface shapes, and how to collect data based on simulations.

With the appropriate guidance from teachers, students are able to use the various knowledge carriers, to look for information in science books, encyclopedias and maps; to collect information in different locations and from different sources, e.g., in the real environment, museum exhibitions, popular science TV programs, advertisements; to interpret and discuss the obtained information; to create and interpret simple figures, data sets, diagrams and charts. It is important that students should appreciate that the quality of data depends on the source it comes from and on the method of data collection, and understand what makes a piece of information scientific.

In diagnostic assessments, we may evaluate students' interpretation of experiments and their analysis of data and diagrams (Task R52 and R53).

Task R52

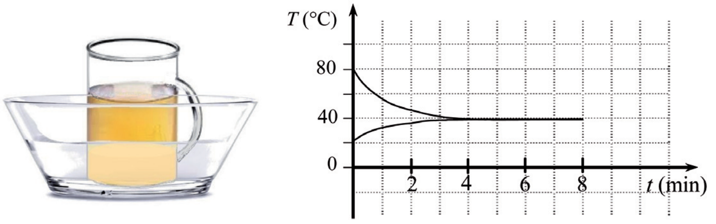
We put a candle in a dish, then cover the dish and measure its mass. Then we light the candle and then cover the dish again. A couple of minutes later the flame goes out. We weigh the closed dish − with the candle in it − once again.



How did the mass of the dish change after the burning of the candle? Justify your answer. What does this experiment prove?

Task R53

We put a mug full of hot tea into a bowl half full of water. The graph shows the change in temperature over time.



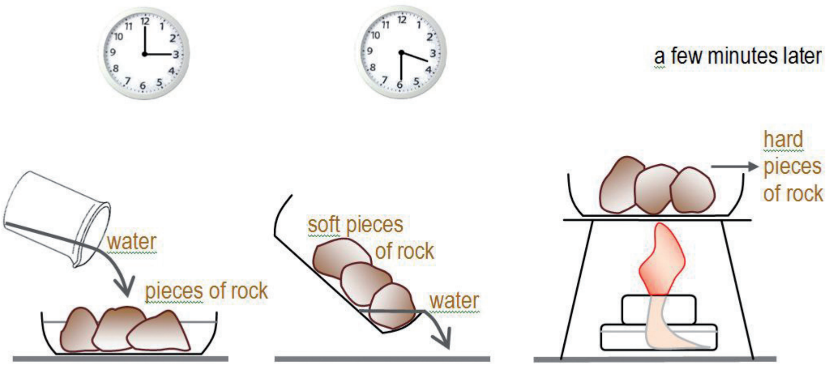
Using the graph, explain the changes in the temperature of the tea and the water.

How would the curves in the graph change if we also plotted the data measured later in time?

In Grades 5–6 students learn to handle two or more variables with ease, to understand logical relationships and to predict changes based on their previous experiences. They are beginning to learn to formulate hypotheses and to test simple ones (Task R54). At this stage they are able to pinpoint the important factors in complicated environmental situations and filter out irrelevant information.

Task R54

Peter examined a piece of rock. He smelled it and then tried to crumble it. He thought it was clay. He tried to test whether his hypothesis was right. His experiment and experiences are illustrated in the pictures below. Study the pictures. Did the experiment confirm Peter's hypothesis?



We may ask students to design experiments without specifying the necessary materials or tools, thus letting the students decide what to use (Task R55).

Task R55

Design an experiment to determine the average density of an egg.

Materials needed:
Tools needed:
The process of the experiment:
The calculation of the average density:

Diagnostic Assessment of the Application of Science Knowledge

The application dimension of the assessment of science knowledge describes those elements of scientific literacy that are required for success in everyday life and for decision-making based on knowledge of science. The dominant elements of knowledge of personal and social relevance include the understanding of evidence, the assessment of its value and knowledge of the scientific background and social consequences of technological processes. The application dimension of the detailed content framework focuses on the interpretation and application of basic science concepts, facts, and relationships in everyday situations; in addition, the near transfer of knowledge, i.e. its application within a school context is also discussed. Rather than attempt to cover all content areas, the present section provides examples for methods and tasks that can be used to assess the application of science knowledge in the system of contexts summarised in Figure 4.2.

Knowledge Application in School Contexts

The application of knowledge in school contexts is tightly linked to the content demarcated by the subject matter to be taught. The development and assessment of application may be performed using the types of task usually used for the evaluation of subject knowledge. The tests follow the logic of science and use the terminology of science disciplines.

Especially in Grades 1–6, when science education is integrated, but also at later stages, when science is taught by disciplines, it is of crucial importance to establish connections between different topics and school subjects. Several studies have demonstrated that near transfer of knowledge is not an automatic process; it should be encouraged and taught. Near transfer may be improved by consciously aiming to point out connections and relationships to show that the various elements of knowledge build on each other, to refer back to things previously learnt and to mention issues that are connected to the subject matter under discussion but will only be dealt with later. A concentric or spiral syllabus design helps to create connections within science topics, as do cross-curricular learning goals and exercises.

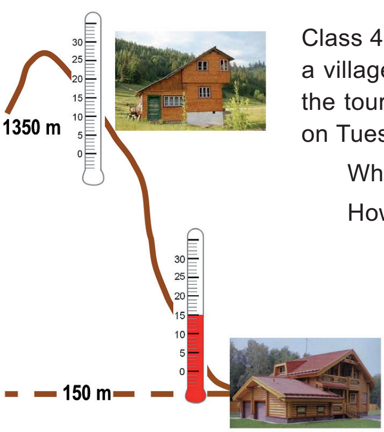
The connection between mathematics and science is well known: the elements of mathematical knowledge, e.g., counting skills, direct and inverse proportionality, calculation of percentages, conversion of measurement units, set operations, functions, combinatorics and probability theory may be applied in several areas of science, e.g., determination of the relationships between physical quantities; calculation of different quantities; analysis of data sets; plotting data; extrapolation. Tasks A1, A2, and A3 show examples of the application of mathematical skills in geographical topics.

Task A1

What is the average daily temperature if the following values were measured during the day?

–3°C –1 °C 15°C 8°C 4°C

Task A2



Class 4 goes on an excursion. They are staying in a village in the valley. They'll leave the village for the tourist hostel located near the peak of the hill on Tuesday.

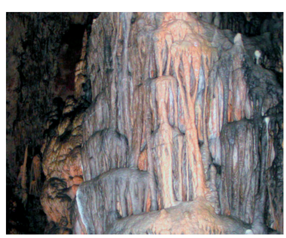
What is the temperature in the village?

How much is difference in height above sea level between the two locations?

What is the temperature at the tourist hostel if there is a 1°C decrease in temperature for every 200 m increase in altitude? Mark the temperature on the thermometer.

Task A3

The fastest growing stalactites grow 2 mm a year. Will the stalactite reach from the top to the bottom of the 2 m high cave in the lifetime of your future grandchildren?



There are several opportunities to develop and assess knowledge transfer between different science disciplines. The following topics of geography require the application of knowledge learnt in physics: the hydrologic cycle; the formation of types of precipitation; the warming, flow, humidity and pressure of the air; the surface-shaping work of the wind and water; the angle of the Sun's rays and the reflection of light (Task A4).

Task A4

The Moon is a celestial object easy to observe in a cloudless sky. Why does the Moon give out light?

There are frequent electric discharges on the Moon.
Its surface reflects the rays of the Sun.
There are a lot of fluorescent materials in its surface rock.
Its craters collect the light of the stars.

Knowledge of physics is necessary to understand several topics related to biology, such as respiration, transport of materials, thermoregulation, the navigation of insects and birds. A particular physical concept may be relevant to several school subjects. The concept of evaporation, for instance, is used in Task A5, where the economic relevance of the water cycle must be described, and in Task A6, where it is needed to explain the process of thermoregulation in a living organism (Task A6).

Task A5

Some of the precipitation seeps into the ground, while some of it evaporates. The table below shows the values measured in 2004.

Settlement	Annual rainfall (mm)	Annual evaporation (mm)
Túrkeve	529	470
Szombathely	700	520

Explain why the gardens around Túrkeve needed to be watered more.

Task A6

When we feel warm we sweat as a result of the functioning of the sweat glands. How does sweat cool down the body?

The study of science often requires the operation of knowledge transfer between chemistry and biology contents. Knowledge of chemistry is necessary, for instance, to learn about the materials making up the body of a living organism, for choosing food (Task A7), and to understand the processes of cellular biology and biochemistry.

Task A7

Several types of yoghurt are available in the shops. Which of the types listed below…

has the most healthy composition?
is the least fattening?

Justify your answers.

in 100 g product	Kiddie Yoghurt	Fruity Yoghurt	Nice Yoghurt
Energy	84 kcal	97 kcal	50 kcal
Protein	3.0 g	3.0 g	4.7 g
Carbohydrates	12.0 g	15.0 g	7.5 g
Fat	2.7 g	2.5 g	0.1 g

Biology and geography have several points of intersection: for instance, soil is discussed as an environmental factor in biology, and in geography the origin and the types of soil are learnt; students may be asked to link what they know about communities from biology to what they have learnt about climate zones (Task A8).

Task A8

Compare oak forests to pine forests based on the following criteria.

Annual mean precipitation
Annual mean temperature
Nutrient-content of the soil
Canopy density
Underbrush abundance

Knowledge of science may also be exploited in non-science subjects. In history classes, for instance, students may search for the biological and social reasons for the emergence and spread of infections and epidemics; in grammar and music classes, students may use their physical and biological knowledge on sounds and articulation. To understand the experiences of PE classes or other physical activity, i.e. the phenomena accompanying intensive exercising (the change in heart rate and muscle soreness), students need to apply the knowledge they have acquired about blood circulation and muscle function in biology classes (Task A9).

Task A9

Andy swam 2 000 m yesterday in his swimming class. The water temperature was 21°C, but he got very warm and his face flushed. Why?

He felt cold after swimming, when he got out of the water. Why?

Knowledge Application in Real-Life Contexts

Far transfer of knowledge reaches beyond the context of classroom exercises; its operation requires the linking of everyday and academic science knowledge. For students to be able to apply science knowledge acquired at school, it must be demonstrated to them that science strives to describe reality. One way to do this is by linking everyday phenomena and scientific explanations in tasks where the solution requires the application of science knowledge. What makes the solution of realistic tasks more difficult is that the transfer of knowledge acquired at school following the logic of science disciplines is not automatic either. Everyday and classroom knowledge are often separated in students' representation of knowledge; a different meaning is attached to the same term in everyday life versus in scientific terminology, e.g., a flower is a flowering plant in the garden versus the reproductive organ of a flowering plant in a biology class. A further source of difficulty is that everyday problems are complex, they cannot be grouped into disciplines, and their resolution often requires the simultaneous application of knowledge in several areas of science.

Knowledge application representing social expectations may be assessed through tasks where phenomena related to science and technology are interpreted, and problems embedded in everyday situations are solved. Typical examples are complex tasks that require the recognition of the social and economic consequences of science phenomena, and link science with other disciplines. However, the use of these tests should be limited in Grades 1–6 as children of this age may not be ready for them.

Tasks assessing knowledge application in a real-life context usually avoid scientific terminology; they use the toolkit of everyday communication. Students' quality of knowledge is often tested through open-ended tasks. Depending on the given task, solutions may reflect varying depths of knowledge, ranging from answers based on personal experiences, e.g., Task A20 to scientific answers, e.g., Task A42. Scoring schemes may use a 2-point scale (incorrect answer: 0, correct answer: 1 point), or a multipoint scale, e.g., Task A57. The points of a multipoint scale may be determined by categorising responses through repeated task calibration.

Application of Knowledge in Real-Life Personal Contexts

Personal contexts are provided by authentic situations with direct relevance to the students, i.e. typically experienced in their immediate surroundings, personal or family lives or in their interactions with their peers. Students have to solve problems, answer and explain questions that they are very likely to have encountered in their everyday lives. The different topics of the content areas learnt at school (Non-living and Living Systems and The Earth and the Universe) offer different opportunities in each school grade for the assessment of the application of knowledge. The complexity of the tasks and the activities increases with the accumulation of knowledge in school science and with the development of thinking skills.

Assessment of the Application of Knowledge through Tasks with Real-Life Personal Contexts in Grades 1–2

Students can receive step-by-step guidance in learning to use what they have learnt at school in making various decisions and solving tasks in a non-classroom context. Tasks involving phenomena and situations well known to the students from their everyday lives may be given as early as Grades 1–2 provided that they are multiple choice questions, where a set of answers are offered.

In the content area of NON-LIVING SYSTEMS, the application of knowledge can be assessed through tasks involving connections between the materials of everyday objects and their functions (Task A10), the selection of the appropriate measuring tools (Task A11); the recognition of the changes of state of water in everyday situations, e.g., the ice-cream melts, wet hair dries, the bathroom mirror gets steamed up, or in natural events, e.g., the formation of precipitation types. Task A11 can be easily transformed into a problem-solving task, which can be given mainly to students in the other two age groups, if for instance students have to figure out what kitchen tools could replace a measuring jug used to measure volume (When measuring the ingredients, Dorothy broke the measuring jug. With what and how can she measure the oil and milk for the cake?).

Task A10

What properties should the materials have to make the objects below?

heat-proof   water-proof   magnetic   elastic   clear




snow boot   kitchen glove   spectacle lenses   ball

Ingredients
900 g flour, 200 ml oil, 0.5 l milk, 50 g yeast, 1 teaspoon salt

Task A11

Dorothy's mother is making a cake. She asked Dorothy to help her and measure the ingredients. What kind of tools will Dorothy use to measure them?

We may test whether students can identify solution making in everyday life, e.g., putting salt in the soup, or sugar in the tea, making lemonade; and name the causes of everyday changes, e.g., a plate breaks, a balloon bursts, the tea water is boiling, and the consequences of these events (Task A12).

Task A12

Peter went on an excursion with his class. He slipped on the stairs of the lookout tower and his backpack tumbled down. He had a phone, a tea bottle, a pair of binoculars, a sweatshirt and a sandwich in the backpack. Select the changes that could have happened because of the backpack falling down the stairs.

His phone battery went flat.
His tea bottle broke.
His binoculars broke.
His sweatshirt stretched.
His sandwich turned mouldy.

The tasks assessing the application of knowledge related to the topic of energy may refer to energy-changes experienced in everyday life, to the phenomenon of burning, to flammable materials (Task A13), and to the choice of the type and location of a light source (Task A14).

Task A13

Which object may catch fire and start a house fire?

newspaper   kitchen-cloth   tea mug   napkin   frying pan

Task A14.

Rose would like to put her new reading lamp in the best place on her desk.

From which direction should the light fall on the paper if Rose writes with her right hand? Why?

from the right   from the left

Mark the place of the reading lamp on the desk.

With respect to application, the important tasks related to LIVING SYSTEMS are those that may be used to assess whether the students are able to recognise the importance of plants and animals from the point of view of man and other life forms, e.g., What role do parks have in a city?. The tasks may be associated with healthy lifestyles and personal safety, e.g., an analysis of the students' daily/weekly activities in the context of healthy physical exercise; the identification of the influences damaging our body (Task A15); calling for assistance (Tasks A16 and A17); choosing safety equipment needed for everyday activities, e.g., cycling or roller skating.

Task A15

We do things that damage our health on a daily basis. What do these activities damage?

We listen to loud music through earphones.	
We read in a poorly lit place.	eyesight
We study sitting hunched over the desk.	hearing
We sit a lot in front of the computer.	posture
We regularly carry our bag over the same shoulder.	

Task A16

Who should you call for assistance in the situations mentioned below?



Kate has broken her hand during training.
A thick smoke is coming from the flat next door.
A heated quarrel has started on the tram.
The storm has uprooted a tree.
A bicycle has disappeared from the garage.

Task A17

You have just seen an accident. What do you need to know when you call an ambulance?

the phone number of the ambulance
the name of the injured people
the precise location of the accident
the number of people injured
the name of the person who caused the accident

Related to the content area of EARTH AND THE UNIVERSE, spatial orientation may be assessed through the identification of locations based on verbal/visual information or through drawing a map or plan to suit a given action plan, e.g., rearranging the room. Temporal orientation may be measured through the creation of ordered sequences from everyday life. Task A18 assesses students' ability to assign various activities to specific months of the year. A more difficult version of the task is if the names of the months are omitted and students are asked to put the events of a year in the correct order. (In what order do the events follow each other in a year?) We can also assess the recognition of the effects of weather on everyday activities, for instance through the selection of the clothing and the planning of the activity appropriate to the given weather conditions (Task A19).

Task A18

Andy got a notebook and took notes. With which months did he pair the following events?

February	we paint Easter eggs
April	we go on a holiday
July	we decorate the Christmas tree
September	we make a fancy dress
October	the new school year begins
December	

Task A19

Luke is going on a one-day excursion one morning in October. The weather forecast has promised a bright, sunny day with 18°C at noon, and moderate winds. However, it was chilly early in the morning, with even some rain at dawn. What clothing should Luke wear to keep him warm in the morning without overheating him at noon?

sweatshirt T-shirt shorts jacket gloves shirt jeans

Assessment of the Application of Knowledge through Tasks with Real-Life Personal Contexts in Grades 3–4

The application of knowledge is more complex in Grades 3–4; it may be assessed with open-ended tasks the solution of which requires multiple steps. Students in this age group may be given tasks involving simple measurements and a scientific analysis and interpretation of everyday activities and phenomena on the basis of one or two criteria.

When solving real-life tasks, some of the questions can often be answered based on personal experiences. The only way to obtain information on the actual knowledge of the students and on their method of reasoning is to ask them to justify their answers. For instance, even students in Grades 1–2 can select the objects ensuring a safe stay on the beach (Task A20), and know what needs to be done to avoid getting overweight (Task A21). However, whether they know the reasons and have the appropriate science knowledge is only revealed by the justification they provide.

Task A20

Ben is getting ready to go to the beach. Select the objects that he definitely must take with him. Justify your answer.

Task A21

The children talked to the school physician in a science class. They were given a lot of good advice. Which pieces of advice should they observe in order to avoid getting overweight? Justify your answer.

Listen to your teacher.
Eat as much fruit and vegetables as possible.
Have as much physical exercise as you can.
Read a lot.

For both tasks, the quality of answers depends on whether they reflect everyday or scientific reasoning. Correct answers for Task A20: A sunscreen and a hat give protection from the sun, from burning, from a heat stroke and from harmful or UV radiation; for Task A21: Listening to the teacher and reading a lot do not involve physical exercise and/or require little energy. It is worth coding and categorising the different levels of answers.

In the content area of non-living systems, a task related to the properties of materials involves the realisation that everyday objects are made of materials appropriate for their uses, similarly to tasks for students in lower grades. The range of properties can now be wider and an increasing number of science terms can appear in the tasks (Task A22).

Task A22

What properties should the materials have to make the objects below?

power cable air mattress tea cup ski gloves

We may also assess the recognition of the different states of matter: Differentiation between dissolution and melting processes in the environment; differentiation between the dissolution and melting of solid materials (Task A23); the separation of everyday mixtures (solid-fluid, solid-solid) (Task A24), the changes in materials (Task A25).

Task A23

What is happening to the materials below? Complete the sentences with one of the specified words.

The honey mixed in the tea…	
The butter put on a freshly made slice of toast…	dissolves
The salt sprinkled in the soup…	melts
The ice cube put in the orange juice...	

Task A24

We are making deep fried cauliflower in breadcrumbs. We would like to reuse the flour that was left after coating the cauliflower and the oil left after frying. How can we remove…

the pieces of cauliflower from the flour?
the breadcrumbs from the oil?

Task A25

We are making dried prunes. We spread 2 kg of fresh plums in a baking pan, and put the pan in the oven to dry at a low temperature for a few hours.

In what way does the weight of the plum change during drying? Justify your answer.
The dried prunes will be sweeter than the fresh fruit was. Why?

The practical applications and problems of measuring and estimation may be assessed through Tasks A26 and A27. A method used in the PISA surveys for the assessment of knowledge application is that several questions assessing various components of knowledge are asked in connection with a given situation. One of the questions in Task A26*,* for instance, assesses the application in an authentic context of the relationship between filling spaces and particle size. However, the cause of the loss can be explained only by reasoning based on experience.

Task A26

Peeled walnuts   Ground walnuts

We bought 300 g walnuts to make a walnut roll and stored them in a tightly closed jar. Later we ground the walnuts and put the walnut meal back into the same jar.

Why does the ground walnut take up less space? Before making the cake we checked the weight of the walnuts again. Why did the scales show 270 g supposing they were accurate and none of the walnut meal was spilt?

Task A27

Kate wants to make a poppy seed cake. She found the following ingredients in the pantry:

1 kg flour,
about 4 teaspoons of sugar,
1 litre milk,
1 sachet (50 g) of ground cinnamon.

What does Kate need to buy and how much of those things does she need to buy to make the cake?

Poppy seed cake

Ingredients

1 pack of butter
2 eggs
1 cup of sugar
3 cups of flour
2 cups of milk
1 and a half cups of ground poppy seeds
1 sachet of baking powder
one pinch of ground cinnamon

In connection with the topic of interactions we may construct application tasks testing knowledge of the causes of changes, for instance in connection with the flow of gases and liquids or with various types of motion in everyday life (Task A28). The scope of identifying ways of saving energy may be extended to include not only the home environment but also the school or travelling.

Task A28

Peter lives in a small town. He regularly visits his grandparents who live in the next village, at a distance of 10 km.

Now that a cycle path has been built, he often goes there by bike. One day, when he was on his way home he noticed with some surprise that he was much slower than he had been on the way there. What could be the reason?

He was tired.	There was a strong wind.
He had a flat tire.	He was hungry.

In the content area of LIVING SYSTEMS the assessment of knowledge application may include tasks asking for examples for the utilisation of plants and animals in nutrition, health care, agriculture and industry. We may assess the application of knowledge related to environmental conditions in the rearing of plants (Task A29) and animals (Tasks A30 and A31).

Task A29

Before going on holiday Anne closed the shutters to keep the room from getting hot while she was away. When she got home a week later she saw that her cactuses had turned yellow and died. Why?

The cactuses couldn't…

take up oxygen.
produce nutrients.
absorb water.
reproduce.

Task A30

Dan bought two goldfish in a pet store. At home he put them in a 5-litre jar filled with water and fed them. In the morning he was sad to find that the fish had died. What could have caused the fish to suffocate?

Task A31

It was a hot, rainy summer. Hollows and rainwater containers filled up with water. After a while, there was an explosion in the number of mosquitoes causing a lot of trouble for the people living in the village.

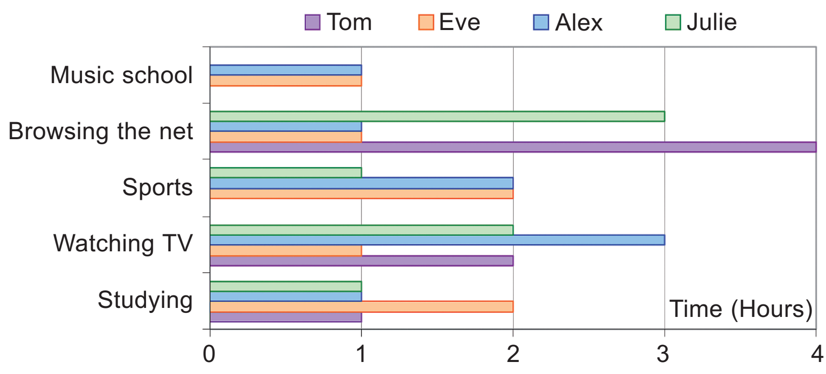
Why were the environmental conditions favorable for the mass reproduction of mosquitoes?

The villagers poured a few drops of oil onto the water in the rainwater containers, and the mosquito the larvae soon died. Why?

In connection with the topic of health protection we may ask the students to plan a daily and weekly schedule of activities keeping the criteria of a healthy diet and sufficient physical exercise in mind, or to analyze a pre-given schedule (Task A32); to identify ways of preventing diseases; and to identify the information about precautions and risks on the labels of everyday products.

Task A32

At the beginning of September, the students were asked how they spent their time after school.



Based on the figure, who do you think should…

spend less time browsing the Internet?
watch less TV?
get more exercise?

Who has the healthiest daily schedule?

Task A33 requires the linking of everyday experiences (illness, taking the child's temperature, having a fever or slightly elevated temperature) with knowledge of the physics of temperature measurement and units of measurement, and with knowledge of the biology of human body temperature and fever (the body temperature may change within certain boundaries; fever is a sign of the organism defending itself).

Task A33

Matthew was not feeling well in the morning. His mother took his body temperature. The thermometer showed a normal value. At noon Matthew had a slightly raised temperature and in the evening he had a high fever. Which values were shown at the different times?

34.3°C	in the morning
36.5°C	at noon
37.7°C	in the evening
40.6°C	
42.1°C	

Why did Matthew's temperature change over the day?

THE EARTH AND THE UNIVERSE: in connection with the topic of orientation in space, we may assess students' ability to plan routes and use symbols by asking them to invent their own system of symbols to transmit spatial information and plan a route based on the given information (Task A34). The identification of the location or situation of spatial elements can be tested through tasks involving localisation based on schematic pictorial maps; tasks requiring navigation based on natural phenomena (Task A35) or with a compass; and students may be asked to give directions based on the cardinal points.

Task A34

Winnie-the-Pooh went to visit his friends. Draw his route. What is 100 m in reality is 1 cm on the map.

First he visited Eeyore, who lives 150 m to the northeast. Mark with the letter E the house of Eeyore in the picture.
He left the house of Eeyore and walked to the east towards the house of Tiger, who lived 200 m away. Mark the house of Tiger with the letter T in the picture.
Then he turned towards the south and walked 300 m to reach the house of Piglet. Mark the house of Piglet with the letter P in the picture.

How many meters did Winnie-the-Pooh travel in total?
How far was Winnie-the-Pooh from his own house at the end of his tour?
In which direction should he walk to get home?

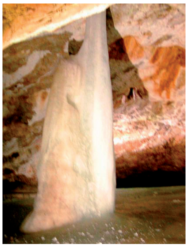
Task A35

The family went for a walk in the Bükk Hills in the summer. They left the tourist path and got lost. What could they use for orientation?

side of trees covered with moss	animal footprints
the position of the Sun	the direction of the wind

The planning of routes may be practiced by gathering information on location. We may ask students to draw a plan of a given location to suit specific purposes, e.g., landscaping of the school yard or designing of an environmentally friendly playground. We may assess students' applicable knowledge of the spatial patterns in changes of weather and in a travelling context, for instance (using Task A36).

Task A36



Charlie and his family are going on a trip to Slovakia at the beginning of August. They are planning to do some sightseeing and to go hiking in the mountains. The Dobsina Ice Cave is among their destinations.

What kind of clothing should Charlie pack for the trip?

In connection with the topic of weather and climate, students' understanding of the relationship between changes in weather and everyday life may be assessed in this age group through tasks involving the selection of the clothing, equipment or personal activity appropriate for given meteorological conditions. We may also ask students to analyze the effects of the Earth's rotation around its axis, that is the of Sun's daily path, on everyday life.

Assessment of the Application of Knowledge through Tasks with Real-Life Personal Contexts in Grades 5–6

By Grades 5–6, students' have acquired the experiences, school knowledge and thinking skills needed for the analysis and understanding of more complex data; they can now identify and apply more complicated and less direct relationships. They are able to consider several different objective and subjective factors at the same time, and to choose between several options. At this age students can be asked to demonstrate their skill in decision-making based on knowledge of and about science, which occupies a prominent place in models of scientific literacy (see Chapter 2). The diagnostic tasks can track the steps involved in the solution and decision making process: the selection of decision criteria, the gathering and analyzing of information allowing the weighing of options.

In the content area of NON-LIVING SYSTEMS, students in Grades 5–6 are not simply required to list the type and properties of material(s) specific objects are made of. We may also ask them to discuss the benefits and disadvantages of making the same object or tool using different materials (Tasks A37 and A38). In addition to functional considerations, economic and environmental criteria may also appear.

Task A37

Why are spectacle lenses made of plastic rather than glass?

Task A38

Fruit juice may be packaged in plastic bottles or in cardboard boxes. What are the advantages and disadvantages of each type of packaging?

Students in this age group learn about further properties of materials, e.g., density, magnetisability, which may be assessed in application tests. In Task A39 a single explanation accounting for three phenomena known from the everyday life has to be found. If their analogical reasoning skills are sufficiently developed, even children in Grades 1–2 can identify the common element of the three events (the chicken fat, the leaves and the logs float on top of the water because they are lighter than water). In order to give an explanation, i.e. that their average density is less than that of water, however, the concept of density must be used.

Task A39

What is the common to the events listed below? Justify your answer.

There are golden yellow patches of fat on the surface of chicken soup.
Leaves cover the surface of the lake.
The logs cut in the mountain woods get to the valley by floating down the river.

The concept of density helps students to understand the consequences of the difference in density between liquid and solid water, e.g., icebergs, life in the water in winter, erosion of stones or freezing of water pipes. Students may be asked to use their knowledge of the magnetisability of materials to identify the appropriate method of separating ingredients in everyday mixtures (Task A40).

Task A40

A lot of bric-a-brac can accumulate in the drawer of a desk over time. Which of the objects can you pick up with a magnet?

pencil   eraser   paper clip   ruler   thumbtack   pin

Students' understanding of the changes in materials and the causes of physical processes occurring in everyday life can also be assessed in contexts based on a wide range of everyday phenomena and experiences (Tasks A41 and A42).

Task A41

Rob opened a packet of wafers and left it on the table. By the next morning the crispy wafers turned soft. What caused the change?

Anna ate a bread bun for breakfast, and left the others on the plate. In the afternoon, when she got home from school, the buns left on the plate were so hard, she couldn't eat them. What happened to the buns?

Compare the two changes. What is similar and what is different between them?

The interpretation of dissolution appears in a more complex form in Task A42. To find the solution the student must know that making cocoa is a dissolution process influenced by the temperature of the milk and blending.

Task A42

Sam drinks cocoa every morning for breakfast. He mixes two teaspoons of instant cocoa powder into a mug of warm milk. He was late for school on Tuesday, so he left half of his cocoa. In the afternoon, when he was drinking what was left, he saw that the colour of the cocoa was lighter, and a brown layer settled at the bottom of the mug.

What kind of process took place with the cocoa powder when Sam mixed it in the milk?
What may have caused some of the cocoa to settle at the bottom of the mug by the afternoon?

We may create tasks where knowledge of the ingredients of food, the change and decay of the ingredients is needed to decide in a typical buying situation which product to choose or whether it is safe to buy a product in terms of considerations of health. In Task A43 various factors can be considered to decide whether Eve made the right decision when she bought the price-reduced orange juice that had a best-before date preceding the date of the party. In this authentic situation students may reason based on scientific, e.g., food may go off, which is dangerous and non-scientific, e.g., retail price considerations, or their combination. To answer the question, students must know the meaning of 'Best before:' written on the box. This knowledge relies in part on everyday experience and in part on knowledge acquired by at school.

Task A43

Eve was organising a birthday party for October 12th. She was buying some juice for the party. Her mother reminded her always to check the best-before date when buying food. Eve took a box of price-reduced orange juice from the shelf with the following label:

BEST BEFORE: 09. 10. 11.

What does this mean?

The orange juice.....

should be consumed before 9th October.

keeps its vitamin content until 9th October.

shall be kept in the fridge after 9th October.

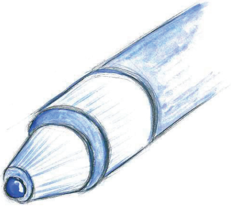
Eve bought the orange juice. Did she make the right decision? Justify your answer.

For Grades 5–6, the content area of NON-LIVING SYSTEMS provides opportunities for the assessment of the application of science knowledge in several other topics as well. These include, for instance, the recognition of the force exerted by the flow of liquids or gases, the link between this force and the weather or the surface shaping work of the wind or the flow of water; the identification of the effects of fluid resistance on bodies in motion (the explanation for the shape of cars and aeroplanes). Students are also able to explain the operation of some simple machines. This provides an opportunity to recognise physical laws in certain operations and lays the foundations for understanding of more complex technological processes. These include, for instance, the explanation of the generation and propagation of sound; establishing connections between the human vocal organs and those structural components of musical instruments (violin string, drum disk) that play a role in sound generation; and understanding the mechanics of a ballpoint pen (Task A44).

Task A44

The ballpoint pen, or biro, was invented in the 1930s by László Bíró, a Hungarian writer and artist. He designed a special pen in which a steel ball covered in ink rolls around and leaves traces of ink on the paper as it rolls.

Kate's ballpoint pen leaks so there were ink stains on her hand and exercise book after doing her homework.



What may cause the excess ink to leak from the pen?

In the content area of LIVING SYSTEMS, the tasks assessing knowledge application in Grades 5–6 may test the application of elementary level knowledge of microscopic organisms. Students may be asked to give examples for their presence in our environment and their beneficial and harmful effects. An example is shown in Task A45, where a scientific explanation needs to be given for everyday rules related to the storage of food.

Task A45

Several foods decay quickly, within a few of hours or in 1-2 days, if kept at room temperature (20°C). Why is food kept fresh longer in the refrigerator?

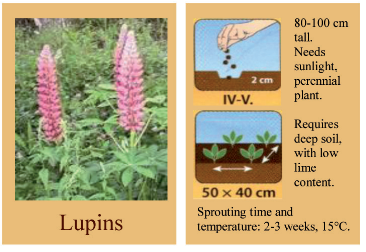
Because by keeping food at about 4°C, we can slow down…

the degradation of vitamins.
the multiplication of microbes.
the drying out of materials.
the motion of particles.

Application tasks assessing students' understanding of the many-sided role of living organisms are also important for topics related to other groups of living organisms, namely plants, animals and fungi (the role of plants in health preservation, agriculture and industry; the role of animals in the life of man, agriculture and industry; the significance of fungi in health care, agriculture and industry). The knowledge students acquire in the classroom about the conditions of life of plants and animals can be straightforwardly applied in the context of choosing and taking care of living organisms in the surroundings of children (indoor plants, garden vegetables, pets) (Tasks A46 and A47).

Task A46

Dorothy bought some flower seeds. Of the garden plants available, she chose lupins because she liked the plant on the packet very much. At home her mother told her that she had picked a nice flower but there was no point in planting the seeds that year. Why?



Dorothy put the seeds away. Next year she planted them following the instructions on the packet. Did the seeds sprout? Justify your answer.

Task A47

Jim and his brother furnished a fish tank. Some time later they noticed that the wall of the aquarium was green.

What could have caused the change?

How can they prevent this change from recurring?

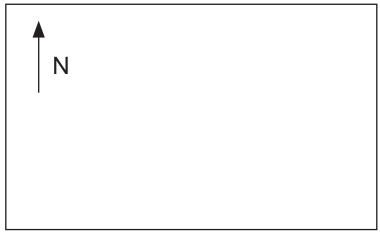
Topics related to knowledge of healthy lifestyles and health studies are also included among the contexts of application tasks used with this age group. These include, for instance, the application of students' knowledge of the adolescent muscoskeletal system, e.g., the dangers of weight-lifting and body building in the selection of sports and training methods; the comparison of the actual eating habits and physical activities of the children to what is generally accepted and recommended for their age; ways of decreasing the risk of accidents at home, in the school and in other communities; the use of efficient personal health strategies, e.g., adequate sleep, ergonomics, safe sunbathing, washing hands or hearing protection. Topics having social relevance: The recognition of reliable information and its sources concerning the effects of alcohol consumption, smoking and other drugs; the analysis of the effects of environmental conditions on personal health; the identification of the internal and external factors affecting personal health habits.

In the content area of THE EARTH AND THE UNIVERSE, there are plenty of opportunities to assess the application of the knowledge acquired about the topic of spatial orientation. Some examples are drawing a plan for the reorganisation of a space in real life; navigation in unfamiliar terrain using a schematic map and route; navigation in real terrain or in virtual space; identification of locations based on map illustrations; using map symbols for orientation; finding a site on the map using the index, its identification on maps of different function using a search network. Task A48 assesses the relative positioning of spatial elements in an everyday situation where directions are requested.

Task A48

Some tourists got lost in a big city and asked for directions. They tried to draw the information given by the person they asked. Try to replicate the map they could have drawn. The arrow indicates north.

They were given the following directions: ‘Follow this road straight to the north for two blocks. Turn left at the traffic lights, then take the third street to the right. You’ll have to walk 300 m and you will see the hotel opposite the church.’



A common authentic situation is to plan a route using information provided by a map, e.g., topographic, administrative and tourist maps (Tasks A49 and A50). Orientation in space and time may be assessed at the same time by asking students to predict travelling time based on the spatial distance information provided by the map, or to the analyze different route options between the place of departure and the destination.

Task A49

Kate was invited by her friend, Anna to a birthday party. Kate had never been to Anna’s before so she asked her how she could get there. She got the following answer:

We live in 22 Otello Street. You can come via Tómellék Street, Muskotály Street or Csabagyöngye Street.

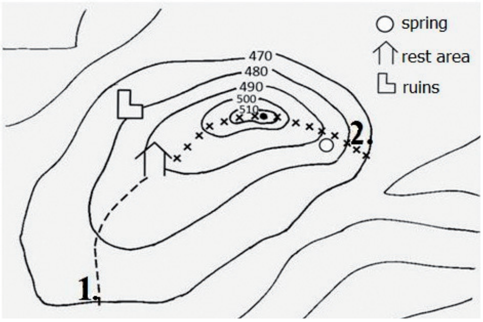
Kate checked the map to see which was the shortest way.

Write down her route.

To solve *Task* A50 the students first have to read the map to find out that there is a larger difference in elevation in Route No. 2. Then they should conclude that this route is steeper, which takes more effort, so progress will probably be slower. The selection of the preferred route provides an opportunity to contrast arguments based on objective (it is less steep, there are resting areas, etc.) versus subjective (the scenery is more beautiful, it is more comfortable, etc.) criteria.

Task A50

The members of the walking club are organising a walk to the nearby lookout tower. They may get to the lookout tower via two routes. After looking at the tourist map there was some debate about which route to choose.



Dan: We should take the shorter one, Route No. 2, because we will arrive sooner.

Kate: That may be the shorter route, but not necessarily the quicker one.

What did Kate have in mind? Why might it take longer to reach the lookout Tower via Route No. 2?

Which route would you recommend to the students? Justify your answer.

Orientation in space may be easily assessed through making models. Student may build models using sand, plasticine or paper based on a given design or blueprint, e.g., of a geological basin, transport network, or a hydroelectricity plant and its surroundings.

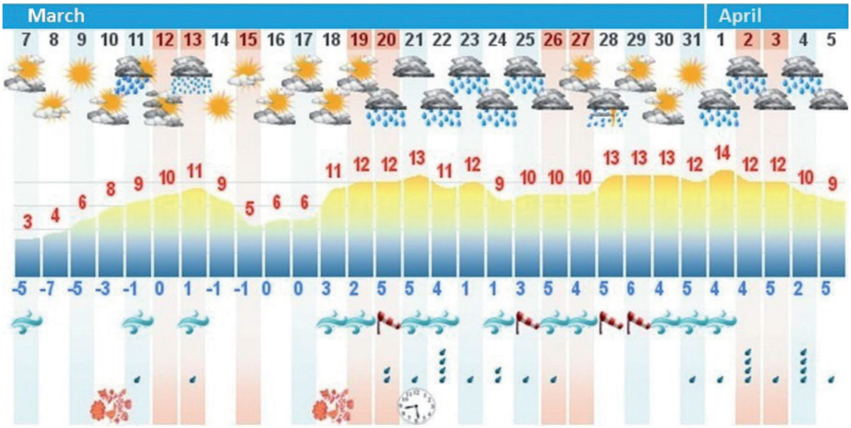
An example for the analysis of pictorial information and reading diagrams is shown in Task A51. In order to solve the problem, students need to apply their knowledge of climate and changes in its components in their personal lives.

Task A51

The students in Grade 6 are going on a four-day trip to the woods in March. They checked the 30-day weather forecast and selected two dates.

March 8–11. March 28–31.

Look at the diagram and write down two arguments supporting these dates.



Decisions based on knowledge of science and scientific literacy play an important role in knowledge application. Task A51 is made somewhat easier by providing a set of answers to choose from and by specifying dates. This way students can only reason based on the given weather forecast, and cannot include subjective considerations unrelated to science, e.g., free weekend. In another version of the task, students may be asked to select the four days that they consider to be the most appropriate themselves, and to list the considerations used to make their decision, and analyse the data discussing along which of the criteria their preferred four-day period is the best option, and along which criteria it is not an ideal but still acceptable option.

Application of Knowledge in Real-Life Tasks with Social Contexts

The application of science knowledge may be assessed in context areas that have a direct role in the maintenance and evolution of society, and in learning to behave and think as responsible citizens. As was mentioned at the beginning of Chapter 5, as early as at the first stage of science education, students can acquire science knowledge and, with the help of examples, recognise basic relationships that establish the foundations of their understanding of the relationships between science, society and technology. In Grades 5–6, a few fundamental questions of science having social relevance are discussed in a simple form. The tasks are relatively simple to start with and become more complicated towards the end of this period. Open-ended questions, tasks asking for students' personal opinion, justification and arguments are popular choices.

When choosing situations or contexts for tasks assessing the social dimension of knowledge application, we should follow the lead of the PISA surveys in that besides social considerations, we should also keep in mind that these situations and contexts should be familiar, straightforward, interesting and important for the students, that is, they should be matched to the students' experiences and the developmental stage of their cognitive abilities. Most of the phenomena and events that qualify as social contexts are not part of the daily lives of students in Grades 1–6; as students do not have direct experience of these situations, they are not authentic problems. This is particularly true for global issues, which concern mankind as a whol, e.g., the overpopulation of the Earth, the problem of energy resources or drinking water supplies. Since they require a considerable body of disciplinary knowledge, complex reasoning and the amalgamation of science with other areas of study, the parallel consideration of social and economic factors, the use of tasks set in a global context should be limited in Grades 1–6 taking the characteristics of this age group into consideration. The recognition of the complex relationships between science, society and technology, the analysis and evaluation of the social and economic effects of science research, knowledge of complicated technological procedures, and evidence-based decision-making with scientific and other factors taken into account should be required only at a later stage, towards the end of science education.

Assessment of the Application of Knowledge in Social Contexts in Grades 1–2

For this age group, social issues are related to the immediate surroundings of the students, to situations that the students understand and to activities that they practice themselves. We may ask students, for instance, to apply the rules of waste collection (Task A52), or to identify the most energy-efficient solution among a few simple technologies known to the students; for instance to identify economical ways of using drinking water (Task A53), electricity and natural gas (used for cooking and heating).

Task A52

In your school waste is collected in different bins for recycling. Put the types of waste in the appropriate recycling bin

advertising leaflet
used tea bag
yoghurt pot
apple core
receipt

Task A53

Clean drinking water is getting more and more precious on the Earth. When do we save water and when do we waste it?

We wash the dishes in running water.
We repair the leaking tap.
We collect rainwater for irrigation.
We close the tap carefully.
We take a bath instead of a shower.

We may assess the recognition of the connection between the natural and the social environment even in this age group; we may ask for examples demonstrating that man is a part of the living nature and his activities affect his environment, e.g., cutting down trees or polluting rivers. Tasks involving the breakdown of a process into phases and the ordering of the individual steps, such as the creation of a simple algorithm, e.g., planning a daily schedule or the identification of the individual steps of a well-known activity, e.g., making tea prepare students for understanding of technological processes.

Assessment of the Application of Knowledge in Social Contexts in Grades 3–4

Besides the issues affecting students' immediate surroundings, e.g., the importance of environmental protection or protected local natural treasures, social and global issues also appear in the curriculum. These include the harmful emissions in transportation, energy production, agriculture and industrial production; waste recycling; environmentally friendly industrial production, life style (Task A54). With the help of concrete examples, students are able to look for links between human activities and the vulnerability of the environment (Task A55); to link the utilisation of materials and energy and the accessibility of the natural environment to the level of advancement of science and technology; they recognise the role of people in the shaping of living conditions of life forms around them, e.g., bird feeding or wildlife protection. It is important that students should pay attention to news about the environment, form an opinion on various problems and their solutions, and practice organising technological processes through everyday situations. This includes for instance the breakdown of activities known to the students (doing the homework, shopping) into steps, the ordering of the individual steps (Task A56), or the construction of a simple sequence of activities using given materials or operations, e.g., ordering of flash cards representing the steps and materials needed to butter a slice of bread or the construction of another 'product' by modifying certain steps or materials.

Task A54

You can buy more and more organic vegetables and fruits nowadays.

Why is it recommended to consume these?
Why do we say that organic farming is environmentally friendly?
Why are organic products more expensive?

Task A55

Ron and his family went on a walk to the Pilis Hills. They passed by the sign shown below. Later when they reached a clearing in the forest, they decided to make a campfire and cook some bacon.

Since there hadn't been any rain for two months, they found a lot of dry logs. They built a fireplace in the middle of the clearing with large stones around it, cooked the bacon, and then put out the fire.

What mistake did they make? Justify your answer.

What could have been the consequences of their actions?

Task A56

The children decorated Easter eggs. One of the groups coloured their eggs red using egg dye, the other made pink eggs using rosehip tea. Select the steps that were performed by both groups during egg decorating.

They carefully washed and rinsed the eggs.
They boiled the eggs in salty water for 10 minutes.
They mixed the powder dye with hot water and a tablespoon of vinegar.
They left the eggs in the dye for 15 minutes.
They made rosehip tea.
They soaked the eggs in the tea for 20 minutes.
They varnished the eggs with oil or fat.

Why are natural materials like rosehip, the outer layer of red onions or orange peel recommended for egg decoration?

Assessment of the Application of Knowledge in Social Contexts in Grades 5–6

In Grades 5–6, several examples can be provided to show that man not only accommodates to his environment but also modifies it. We can help students to realise that people are responsible for the effects of the shaping and modification of the environment and for the sustainability of the environment; that the condition of the environment and people's health are not independent of each other. Students are able to understand that everybody is responsible for his or her own health and for the health of others; they can recognise the relationship between daily habits and lifestyle on the one hand and future health and life prospects on the other, that is, the effects of the present on the future.

At this age students are ready to discuss more complicated issues of environmental protection, which are not necessarily experienced in their immediate surroundings. These include noise pollution, heavy metals and nitrates polluting fresh waters and soil; solid particles and gases polluting the air; depletion of minerals and non-renewable energy sources; alternative energy sources; the environmental and social consequences of global warming. In this age group, a discussion of topics of environmental protection includes an analysis of its effects on the environment and living organisms, and the studying of the ways of preventing and correcting damage.

We can help students understand the relationship between science and technology by showing them the uses of various materials, e.g., the relationship between the properties of usable rocks, minerals and energy sources and their usability and the way new materials and tools can be developed for a specific purpose, e.g., space research, telecommunications or medical instruments. Students in Grades 5–6 can learn about the environmental, economic and social effects of industrial-level production, and the positive and negative effects of technological development if these processes are illustrated by examples. For concrete situations and relatively simple problems, students can be expected to analyze information and data, make decisions, choose between a set of possible solutions and justify their choice. Students' attitudes towards scientific research can be shaped by telling them about cases that give them an insight into the life and work of scientists, and illustrate the effects of their discoveries on everyday life and social development. Every science discipline offers opportunities for students to recognise the importance of scientific research in the solution of environmental problems and in the protection of the natural and the man-made environment; and to see how scientific knowledge can be applied in everyday life.

The assessment of the application of knowledge in Grades 5–6 may include tasks asking students to think of examples of materials with different properties used in various areas of life, e.g., medicine, space research, information technology, automotive, food and building industries; examples of research programmes developing materials having new properties for new functions, e.g., different types of plastic, semiconductors and superconductors. Application tasks concerned with the properties of materials and their uses may also refer to economic, aesthetic and environmental considerations in addition to physical properties (Task A57), and to objects having social functions in addition to practical uses (Task A58).

Task A57

Nowadays a wide range of different products are available to buy. If you shop carefully, you should keep several criteria in mind.

What kind of criteria do we consider when buying outdoor furniture and we can choose between several kinds of outdoor furniture made of plastic, wood or metal? Justify your answer.

Task A58

The traffic signs at level crossings are often stolen by thieves specialising in metal theft, which endangers the lives of other people. What properties should the material possess that could replace the metal in the production of traffic signs? Why?

flexible cheap coloured hard durable

In Grades 5–6 we may tackle complex problems like waste management relying on students' experiential knowledge and what they have learnt in school. In Task A59 several environmental, social and economic arguments may be listed in connection with the use of biodegradable versus non-biodegradable plastics. The arguments and counterarguments listed by the students reveal a great deal about their knowledge, scientific reasoning and emotional attitude towards the subject.

Task A59

One of the biggest problems of our time is the question of waste management. Some packaging is made of biodegradable plastic now. List some arguments for the use of biodegradable and non-biodegradable plastics.

The analysis of the possible uses of alternative energy sources, e.g., natural resources, benefits and disadvantages is one of the fundamental topics in tasks assessing the social dimension (Tasks A60 and A61).

Task A60

Renewable energy sources were one of the topics in the contest organised on Earth Day. The teams analysed the potential uses of the power of wind, the Sun and water in one of the tasks.

What kind of natural conditions are required to produce energy with a wind turbine, solar cell, and hydroelectricity plant?



What kind of renewable energy sources may be used economically in Hungary? Why?

Task A61

As can be seen on a map, Hungary is exceptionally rich in thermal spring water. A thermal spring or hot spring is a spring of groundwater having a temperature of more than 30°C.

Where does the energy of the thermal spring come from?

What are the advantages of using thermal spring water for heating?

From the point of view of the environment:

From the point of view of the economy:

In connection with the topics of environmental protection we may assess the analysis of the effects of human activity on the environment and living creatures, and students' knowledge of the ways of preventing and correcting damage (Task A62).

Task A62

Forest fires are common during prolonged periods of drought.

What damage can a forest fire cause?

Natural damage:

Economic damage:

How can we prevent forest fires?

Most of the problems appearing in a social context are complex; their solution often requires the application of knowledge related to disciplines other than science, e.g., mathematics and economics. One of these complex problems is the recognition of the natural, economic and social consequences of vine cultivation as an agricultural activity, as in Task A63.

Task A63

In the hills of the northern shore of Lake Balaton grapevines were planted in rows running down the slopes near the shore. Shortly after, the stretch of shore nearby was colonised by reed.

Why did the reed appear as a consequence of vine cultivation?

What should we do to mitigate the effects of vine cultivation on the lake?

What are the economic consequences of the proliferation of plants in the lake?

Another everyday problem appears in Task A64 showing an example for the assessment of social issues in connection with the complex topic of transport planning. The calculation of the costs requires the application of mathematical knowledge, and to be able to answer the remaining questions economic considerations, e.g., costs per person, scientific considerations, e.g., environmental pollution and energy efficiency and personal needs, e.g., journey time, and comfort all need to be taken into account simultaneously.

Task A64

A team of gymnasts from a school in Szeged are planning to go to Szegvár, which is 50 km from their town, for the semifinal of the Student Olympics. Their teachers and parents are trying to decide how the team of 38 persons should travel. Should they rent a coach or should they go by car? They constructed the following table to aid their decision.

Calculate the missing data.

	Coach	Car
Number of seats	48 persons	5 persons
Rental fee	5 500 HUF/km	–
Fuel	diesel oil	petrol
Fuel consumption /100 km	30 litres	8 litres
Fuel price	375 HUF/litre	390 HUF/litre
Distance	100 km	100 km
Amount of fuel required	litres	litres
Price of fuel required	HUF	HUF
Cost of the journey	HUF/person	HUF/person

Which vehicle, the coach or the car do the following arguments support?

It is environmentally friendly.
It is energy efficient.
The cost per person is lower.
The journey time is shorter.

Which vehicle would you choose? Why?

Students in these school grades continue to study and analyze technological processes. Task A65 provides an example for the recognition of energy efficient methods in an everyday sequence of actions. Besides the analysis of a pre-determined sequence of actions, we may also ask students to make their own plans, for instance to develop an action plan in connection with environmentally conscious behaviour in the social environment: to organise waste collection in school for recycling, to make a bird protection plan for school, or to landscape the school grounds.

Task A65

We are making grilled chicken breasts with cheese and steamed vegetables for lunch. We take some chicken breasts out of the freezer, which should be defrosted before cooking. We can defrost them in different ways:

We put them in a bowl of hot water.
We warm them in a microwave oven.
We pour cold water over them.
We leave them on the kitchen counter for a few of hours.

Which is the quickest method of defrosting?

Which is the cheapest method?

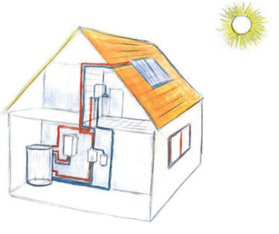
What considerations influence our choice of method if all the tools are available? Justify your answer.

The assessment of students' understanding of technological processes may extend to more complex problems in this age group. Tasks A66 and A67 represent complex problems involving a combination of technological, economic and environmental considerations to assess students' understanding of issues which are topical and likely to be authentic for several children. These tasks also touch upon global issues.

Task A66

Major research and development efforts aiming to harness solar power have been made for decades, but solar panels started to appear on rooftops only a few years ago.

How is solar power harnessed in the family house shown in the picture?



In Hungary, solar panels always need to be supplemented by other types of heating, e.g., gas or wood. Why?

Why is it important to spread the use of solar panels in spite of the extra costs involved?

Task A67

The renovation of panel buildings is supported by the government's panel programme. After the modernisation of doors and windows and the heat insulation of the buildings the flats inside them became warmer, and the residents pay less for the heating.

Why did the heating of the flats become cheaper?

Why is the insulation of panel buildings supported by the government?

Science Content Areas for Diagnostic Assessment

The Assessment of Disciplinary Knowledge in Grades 1–2

Non-Living Systems

Properties of Objects and Materials, the Discovery of Properties

MATTER is the substance of which the physical world is constructed. Knowledge of matter and materials is essential both for science and for everyday life and it is therefore one of the core topics of science education. In Grades 1–6 students learn about the most important properties of materials and material systems (e.g., density, colour, electrical conductivity, hardness, flexibility, thermal conductivity, melting point, boiling point at a given pressure) and about methods of investigating these properties; they learn to characterise states of matter and changes of states; and they discover the relationship between the properties of materials and their uses (e.g., finding the material with the properties appropriate for a specific purpose).

When they start school, students already have a great deal of knowledge of the objects in their surroundings and they have experience of different types of material but their concepts (object, matter, material) are not differentiated at this stage. They often use the word material in an overly narrow sense restricting its reference to, for instance, only the building materials a house is made of. In Grades 1–2, as objects of everyday use are inspected, the concept of object/body begins to be differentiated from the concept of material. This process can be encouraged by listing perceptible properties of objects, e.g., size, shape, length, mass, surface, colour or material, recognising and naming materials and distinguishing living from non-living things based on signs of life. It is important to help students in this age to begin to realise that living organisms (including human beings) are made of matter, as is the natural environment, including the crust of the Earth.

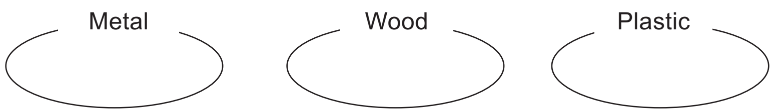
Knowledge of materials and material properties may be assessed by providing students with a list and asking them to select the names of the properties characterising the material of a specific object; to colour the pictures of objects made of a given material or draw objects made of a given material. We may use Task D1 to assess students' ability to group objects by their material, which is more difficult if the students have to identify the types of material themselves. In simple cases, students of this age can also be asked whether a given property, e.g., shape or size is a property of the object or of the material.

Task D1

Sort the objects by the material they are made of.

bookshelf key cardboard box spoon toothbrush

mineral water bottle radiator



A first step towards learning about states of matter is recognition of the three states of water and the observation that the shape of solid objects may be changed by external forces – objects may be broken, bent, stretched, squashed or torn – and there are major differences between objects in this respect.

The properties of materials are studied through observations and demonstrations, which not only help students to get to know materials but also equip them with the skill of measuring physical properties. Every student has some experience of measuring and units of measurement in his or her daily life, for instance, when going shopping, doing the cooking or during a medical examination, but the precise terms of physical quantities, units of measurement, the concepts of measurement, measuring instrument and measurement error are acquired later, during the course of formal education. An essential precondition to learning the units of measurement is familiarity with the proper use of the concepts of length, mass, temperature and volume. Students often confuse the terms mass and weight, and fail to distinguish the concepts of mass and density in their usage of the terms.

It is advisable to practice ESTIMATION with the students prior to measuring: there are several opportunities for this in the classroom. For example the estimation of the size and mass of objects in the classroom, the distance between objects, the temperature of the air, the duration of events; visualisation of one unit of measurement or the estimation of the same quantity using different units of measurements. Students must learn to represent a single unit of measurement appropriately and should be able to link a given quantity with the proper unit of measurement (Task D2).

Task D2

Fill in the missing units of measurement.

The height of the classroom: 3…
The mass of a little bird: 30…
The length of a pencil: 16…
The mass of your friend: 32…
The mass of a car: 1100…
The volume of 1 kg of water: 1…
The mass of your textbook: 0.3…

Besides estimation, the process of measurement may be practiced through playful tasks. Students may invent appropriate tools to measure length or volume, they can use their own body for measuring (e.g., hand span, finger, step), or they can construct measuring instruments using various tools (e.g., a tool to compare objects of different mass created using sticks, wool and small plastic containers). At this stage, mostly mass and temperature are measured and the volume of liquids.

Changes in Materials: Change of State, Mixing, Dissolution, Combustion

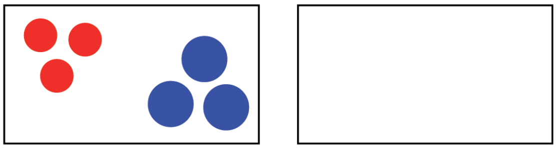
Changes in the properties of materials and objects may be observed through several kinds of observation, demonstration and experimentation. When the students' experiences are discussed, it is important to identify the results of the change (e.g., the rubber band has become stretched, the water has become warmer), the property undergoing change (e.g., length, temperature) and the events that caused the change (e.g., stretching, heating). Initially children focus only on one aspect of the change, but later on they can take several factors into account and recognise reversible operations.

Students have several experiences of CHANGES OF STATE (e.g., condensation of water vapour, freezing of water, melting of ice). They are able to give examples for changes of state and to pair the name of the change of state with the appropriate process. The accurate use of technical terms presents difficulties not only for this age group but for older children as well: the term *melt* tends to be confused with the term *dissolve.* In the context of changes of state, the identification of melting and freezing is the easiest and condensation is the most difficult.

Pure substances are made up of one, while MIXTURES are made up of more than one substance. Mixing is a process whereby we create a mixture from two or more pure substances. In primary education the teaching of mixing has various different goals. Students become familiar with mixtures important in their everyday lives (e.g., tap water, tea, fresh water, soil, air), with simple methods of separating mixtures into their components, and we can lay the foundations of students' later studies – understanding of the difference between mixtures and compounds – by helping them to realise that the components of mixtures retain most of their original properties. Most children have some experience of mixtures when they start school (e.g., a mixture of ground walnuts, sugar and grated lemon peel to make a cake; lemon tea; fruit yoghurt, etc.), and we often use the concept of mixing/blending in our everyday lives. It seems sensible, then, to rely on examples familiar to the students when teaching the scientific concepts of mixing and mixtures and defining the concepts of 'mixing', 'mixture' and 'separation'. At first we should only discuss mixtures that are perceptibly mixtures of different substances (macro-level mixtures). Students of this age are able to identify the mixtures among different objects (e.g., glass cup, wooden spoon, chicken soup, macaroni cheese, plant soil, wet sand, Lego brick), and mixing events among drawings of various operations. Task D3 assesses the elementary level representation of the concept of mixing.

Task D3

You can see blue and red circles in the opposite corners of the frame. In the frame on the right, draw the position of the circles after mixing the red circles with the blue ones.



DISSOLUTION is the process whereby the particles of the solute and the particles of the liquid solvent mix with each other. Students learn to understand the process of dissolution in several stages; its scientific interpretation requires a particle model. Non-conservation type interpretations ("a sugar cube put in the water disappears, turns into nothing") represent an elementary level of children's explanations for the dissolution of sugar and salt. A differentiation between a substance and its property may be observed in several cases: "the sugar has disappeared, but its taste has remained." An interpretation of the type "it turns into water, it turns into liquid" signals a higher level of conceptual development since it reflects the principle of matter conservation.

At this age, knowledge of COMBUSTION is related to personal experiences, observations and the identification of the perceptible signs of burning. Students can tell whether a material known to them from their daily lives is combustible or not; they can learn the rules of extinguishing fires and methods of soliciting help in case of fire. Students' future understanding of changes of materials can be facilitated by using examples at this stage to help separate the concepts of heating and burning.

Interactions

In Grades 1–6, mechanical, thermal, electric, magnetic, gravitational and optical interactions are included in the discussion of concrete phenomena (e.g., temperature equalisation; the Earth's magnetic field; gravitation; light reflection). The study of interactions is greatly simplified at this stage of education, only the interaction between two objects, or an object and a field are mentioned, and within them only those cases where just one interaction is interpreted between any two partners. In Grades 1–2, we may use examples to demonstrate that the properties of objects and materials may be altered by external forces; the objects participating in interactions undergo changes and their states change in opposite directions (e.g., when one body warms up, the other cools down). The most readily perceptible interactions are the motion of bodies and changes in state of motion. Children are able to understand that the position of a body may change and in specific situations they can identify the change in a state of motion. They can give examples for types of motion and distinguish inanimate objects with self-motion from living organisms.

Energy

According to classical physics energy is one of the scalar state parameters of physical objects, and the total quantity of energy applying to all physical objects of the Universe is constant, as stated by the law of conservation of energy. Energy is an abstract concept, the foundations of which are laid in Grades 1–6 with the use of concrete examples. Several research studies have indicated that the treatment of energy, especially of heat, as a material is typical of children's thinking, just as it was in the history of science. Children view energy as something that can be produced, transferred, stored, moved and used. Children in lower school grades often associate energy with living organisms or confuse it with the concept of force. Their lack of differentiation between these concepts is testified by expressions such as a body 'transferring power to another', or a body 'running out of power'.

At the first stage of formal education we may rely on everyday experiences and on children's conception of energy as a material. We may then move on from this conception and show examples for the conservation of energy demonstrating that the use of energy is only a transformation, a manifestation of the energy in another form; energy is not produced or generated, it is only transformed. Students in Grades 1–2 learn about types of energy through everyday examples: identification of fuels, listing of household appliances and means of transport powered by electricity; identification of the effects of electricity on the environment, e.g., a lamp gives out light and heat; recognition of the propagation of light; and finding examples for the energy of motion. In connection with the properties of life, students should learn that food is a source of energy and light is an environmental factor, a condition of life.

Living Systems

Criteria of Life, Properties of Living Organisms

In connection with the content area of living organisms, it is essential to discuss what criteria can be used to distinguish life forms from non-living objects. The content of the concept of living organism contains only a small number of features: it exhibits signs of life, it has a cellular structure, it is inseparable from its surroundings and it forms communities in nature. Life forms include plants, animals, people, fungi and microorganisms.

In the first phase of discovering the world, children believe that everything that moves is alive and disregard the circumstance whether it moves by itself or as a result of external forces. Several studies have demonstrated that young children's concept of living organism excludes objects not performing mechanical motion. At a later stage, children learn that not every object performing mechanical motion is a living being and, conversely, not every life form is characterised by mechanical motion of some type, e.g., running, swimming, flying or crawling. At this stage of development thinking is strongly linked to experience, and most conceptual features are perceptual and tend to apply to only a narrow set of individuals.

Our studies indicate that by the end of Grade 2, the great majority of children can confidently use the concept of life as a distinguishing or exclusory criterion, and only a few remain who consider moving objects (e.g., airplanes, the Sun) to be alive. However, plants and fungi, which do not shift their position by motion, are often excluded from the category of living being. For instance, several children consider bryums, common male fern, and mushrooms to be inanimate objects. By the end of Grade 4, these problems should apply to no more than a few students but naming the superset (living organism) containing various life forms represented by drawings may present difficulties even at the end of Grade 6.

Students in Grades 1–2 tend to believe that potential or fictional entities (e.g., those existing in a story) are real. An ability to draw a distinction between these and real entities is an important precondition of acquiring the concepts of living beings and non-living objects as applied to reality (Task D4).

Task D4

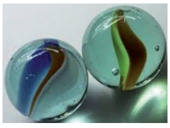
What properties does a fox have in real life?

It is sly.
It is carnivorous.
It talks.
It lives in the wild.
Its body is covered in red fur.

The differences between living organisms and non-living objects may be captured through signs of life in Grades 1–4. Students in Grades 1–2 observe only a few life processes in plants and animals (nutrition, motion, growth, reproduction, death) and rely on these to decide what is alive and what is not. At the end of Grade 2, students' concept of life can be assessed through a task requiring the classification of objects into living and non-living entities (Task D5).

Task D5

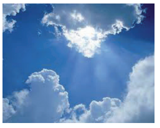
Which of the things in the pictures are alive and which are not? Explain why.


marble


dog


moss


maybeetle

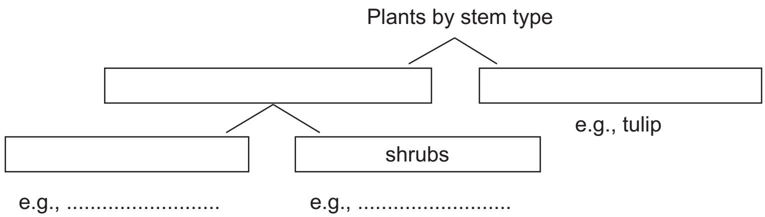

cloud

Body Structure, Classification, Life Processes and Living Conditions of Plants

Plants are a separate group of living organisms distinguished from animals and fungi. They are of less interest to young children than are animals. As children in Grade 1 cannot abstract away from details, they learn about individual types of plant (woody and herbaceous plants). At this stage, the description of plants does not follow the morphological and taxonomic principles of classification but is limited to perceptible, concrete morphological characteristics (size, shape, colour, smell, and surface). The parts of a plant and the differences between woody and herbaceous plants – which constitute the basis of plant classification (Task D6) – are discovered through observation and exemplars.

Task D6

Complete the classification of plants.



Students characterise different plants and identify the best-known types of fruit and flower based on their prior empirical knowledge, without defining the scientific concepts of fruit and flower. The properties taken into consideration in the classification of plants are habitat (forest, field or waterside) and subcategories of habitat (forests: canopy, understory and the forest floor; fields: herbaceous plants, grasses; waterside: woody and herbaceous plants).

Students in Grades 1-2 are familiar with the main similarities and differences between animals and plants. They can list a few, directly observable signs of life (growth, development, reproduction, death). They can link the various changes in the lives of plants to individual seasons, e.g., spring: budding, foliation, blossoming; autumn: development of fruit, loss of leaves, but their observations are limited to external, macro-level changes.

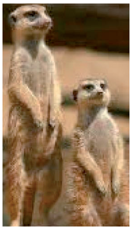
Body Structure, Classification, Life Processes and Living Conditions of Animals

The exploration of the body structure of animals progresses from the description of observable morphological features towards the discovery of the features important from the perspective of biological, evolutionary and taxonomic principles. In Grades 1–2, animals are identified on the basis of their appearance and their main body regions.

Students' knowledge of animal classification starts with their immediate surroundings and familiar animals and expands towards more distant habitats and less known animals. Besides habitat-based classification, animals are also grouped into major taxonomic classes (mammals, birds, reptiles, amphibians, fish, molluscs and insects) on the basis of properties identifying the classes but the taxonomic categories are not labelled at this stage (Task D7). Students also learn about other, non-taxonomic classification; the concept of endangered animals is interpreted with the help of examples.

Task D7

Alex and Vicky were reading about the meerkat. Vicky didn't know what kind of animal the meerkat was. Based on what he read, Alex guessed it was a mammal. Which expressions helped Alex to guess correctly that the meerkat is a mammal?



The meerkat is a small animal living in South Africa. It is 30 cm long. Its coat is usually brownish-grey. It can stand on its hind legs and watch its surroundings for a long time. The mother gives birth to 2-4 live offspring. Young meerkats feeds on their mother's milk until the age of 6 weeks.

With the help of examples, students in Grades 1–2 can understand that the life processes of different groups of animals may be realised in distinct ways and that the life processes and behaviours of animals are influenced by their environment and by the change of seasons.

Structure and Classification of Fungi

The understanding of the place of fungi in the living world and their evolutionary role requires extensive prior knowledge. The first steps are taken in primary school, where what is learnt about fungi is mainly related to their perceptible properties and is limited to their external structure supplemented with their role in everyday life.

In Grades 1–2, children get to know the most familiar species of fungi, the death cap and the horse mushroom. They learn their most important characteristics and which is edible and which is poisonous.

Body Structure, Life Processes and Health of Humans

When the major features characterising people are discussed in connection with the topic of the BODY STRUCTURE AND LIFE PROCESSES OF PEOPLE, it is important to emphasise that human beings should be included in the category of living organisms and within that in the category of animals. Humans are the most developed members of the living world. They are distinguished from every other life form by language (speech) and thinking. It is important to emphasise that people are living organisms and therefore display life processes. For people, too, the realisation of the various life processes is linked with different structural elements. The human body is made up of organs and organ systems, which are specialised for different functions and are closely connected to each other. In this topic area students get to know the main parts of the human body and their functions; the life processes of human beings and their interactions; and the effects of environmental changes on people's lives and the effects of human activity on the environment.

Students in Grades 1–2 know the regions of the human body and their parts and the names, places and functions of the essential internal and external organs in the human body (Task D8). They can name the paired and unpaired organs of perception and their roles, and they can recognise them based on description. Students know that the skin is not only a sensory organ but also has an important role in the protection of the body (Task D9).

Task D8

Link the organs with their roles.

brain	It secretes urine.
stomach	It enables us to think.
kidney	It digests food.
	It circulates blood.

Task D9

Select the properties that signal a change in body size.

shoe size   length of hair   body mass   skin colour
head circumference   eye colour

Students know in what range the body temperature of a healthy person is and at what point we can talk about fever. They learn that people, just like every other living being, exhibit signs of life. Of the life various processes nutrition, motion, birth, growth, development and perception are discussed in more detail. Students not only learn what we perceive with what but also discover how the sensory organs support one other and the recognition of objects. They learn about the basic rhythms of the human body (e.g., heart beat, breathing, feeding, sleep-wake cycle) and distinguish them from other rhythms in nature. They realise that people engender offspring that are similar to them and their offspring are not only similar to them but also to each other. They are also able to recognise that the features of a human organism are influenced by heredity and by the environment.

The goal of teaching the topic of HUMAN HEALTH is to develop students' understanding of the concepts of health and disease. The causes, symptoms and methods of prevention and treatment of diseases familiar to the students are discussed; students' awareness of the importance of modern nutrition and physical activity/exercises in health maintenance is raised. The process of growth and development and the characteristics of sexual health are discussed. The rules of accident prevention and personal safety are taught; the harmful effects of substance abuse (smoking, alcohol and drug consumption) on the human organism are demonstrated. The concepts of mental, emotional and social health are explained, their components, the relationships between them and ways of maintaining them are discussed; the meaning of the concept of personal and communal health is explicated and strategies for their maintenance are introduced.

Students in Grades 1–2 are familiar with basic questions of health and know the essential rules of health maintenance; they recognise the importance of correct body posture and regular physical exercise (Task D10); they know how to prevent common accidents and how to solicit help; they can give examples of substances beneficial or harmful to the human body; and they can identify relationships between the environment and human health.

Task D10

Compare the musculosceletal systems of a child who gets regular physical exercise and a child who does not. Use the relational symbols.

Bone strength:	active child	☐	not active child
Development of muscles:	active child	☐	not active child

Ecosystems

The understanding of the concepts of habitat and ecosystem requires knowledge of living organisms and their interdependence and interactions. Students should understand that there is a strong link between living organisms and non-living environmental factors and also between different living organisms. In Grades 1–2, students learn about ecosystems familiar to them, e.g., forests about their characteristic life forms and conditions, and discover that the living being living in a given habitat (forest, field, park or garden) form an ecosystem.

Environmental Protection, Conservation of Nature

Environmental education is not an independent and isolated component of science education but an integral part of it with interdisciplinary content and system of activities. In Grades 1–2, the first elements of environmentally conscious behaviour are developed, e.g., raising awareness of the diversity of nature and natural treasures.

The Earth and the Universe

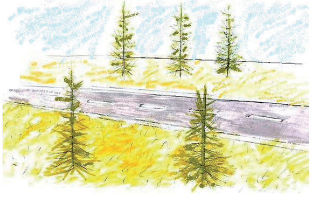
Orientation in Space

The topic of orientation in space focuses on the development of spatial intelligence. In models of human intelligence, spatial intelligence appears as a broad sub-domain or a cognitive ability. In the structure of formal education, the fostering of spatial intelligence moves from close to distant spaces over the school years. It starts with experiences in the immediate surroundings (personal space) (Grades 1–2), progresses through the locality of the home (Grades 3–4) to the interpretation of the various factors of levels of spatial organisation (landscape, settlement, micro-region, county, region, country) in Hungary and the Carpathian Basin (Grades 3–4). Initially, the main emphasis is on the exploration of reality and on orientation in it, the next step is the simple representation of reality, and finally these skills are used for various activities of orientation using a map (and a globe). In Grades 1–2, the activities are based on direct observation and require the simple representation of spatial concepts (e.g., describing, asking a question and drawing landscapes), in which the use of terminology required to express spatial relations verbally (e.g., right-left, up-down) plays an important role.

The development of ORIENTATION IN REAL SPACE may be encouraged in the classroom by asking students to draw an area from different angles and in different sizes or, conversely, to collect information from an illustration. Task D11, where the truth-value of a given set of sentences must be judged, assesses the interpretation of a graphical representation in Grades 1–2. Due to a low level of literacy and difficulties with using technical terminology in this age group, it is best to ask students to select the correct expressions from a list or to group a set of pre-given expressions; the tasks used at later stages require students to supply answers in their own words.

Task D11

Based on the drawing decide whether these statements are true or false.



There are pine trees on both sides of the road.
There are two pine trees on the closer side of the road.
There are two pine trees on the farther side of the road.

The DRAWING of a smaller or larger section of a SPACE requires students to record an image formed on the basis of given information. In Grades 1–2, verbal information is primarily based on subjective comparison and representations are landscape-like.

The basic logic of ORIENTATION IN SPACE is advancing from close to distant spaces, from the known towards the unknown in successive age groups. The conceptualisation of the location and position of spatial elements starts with subjective comparisons and proceeds towards the objective first in reality and then on a map (based on cardinal directions or in cartographic grid systems). It follows that in Grades 1–2 the assessment of students' knowledge should focus on the accuracy and specificity of observations and on the level of description. Diagnostic assessment provides information on students' ability to interpret and use the symbols and codes suitable for representing space. The goal is for students to be able to use any symbol system in a given situation rather than to learn a specific system. In Grades 1–2 students can be expected to name a few geographical places.

To be able to understand the topic of ELEMENTS OF SPATIAL STRUCTURE AND THEIR HIERARCHY, students must have a clear idea of the proportions of a space. The knowledge of interest is not the actual measurements but the orders of magnitude and the relative proportions of spatial elements (e.g., landscapes, countries, still and flowing waters and objects). This knowledge may be acquired through estimations and comparisons following measurement. (Which is bigger? How many times can one be fitted into the other? etc.). It is also in the focus of the diagnostic assessment; the tasks are based on the developmental sequence of estimation – measurement – calculation – abstraction. In Grades 1–2, the tasks mostly require the estimation of the proportions of students' immediate surroundings (Task D12).

Task D12

How wide do you think the road may be where the buses run?

10 cm   1 m   5 m   10 m   half a km

A fundamental component of orientation in space is knowledge of the SPATIAL ORDER OF ENVIRONMENTAL PHENOMENA AND PROCESSES. The fact that environmental phenomena and processes take place in space is experienced by students in their early childhood, but the causes are not discovered until later and the consequences of this fact are the last to be recognised. Assessment tracks this developmental sequence and measures the operations of spatial ordering in consecutive age periods. In Grades 1–2, tasks involve recognition and identification of the order of objects in students' immediate surroundings and events experienced in day-to-day life (e.g., students have to imagine walking in a given direction across a landscape represented in a picture and list the objects and life forms they pass by).

Orientation in Time

In this topic children learn that geographical and environmental phenomena and processes take place in time and their time scales may be very different. Students can easily sense daily and yearly time scales and the passage of time within these periods, since they experience them in several environmental phenomena, and the events of their lives are strongly correlated with them. However, socio-economic processes, historical events and changes in the environment take place over long decades or centuries. Developing a feel for historical time and learning to navigate in it are more difficult for students of this age. They have to imagine the differences of scale between the time familiar to them and the dates and durations of historical events, and learn to represent dates and durations on a time wheel or a time line. To be able to understand when the Earth, the rocks, the structural and surface forms were formed and how long these processes took, students must have a concept of geological time. The development of this concept can be encouraged with the help of analogies, estimations and calculations. From the perspective of culture and anthropology, starting with the Middle Ages people's perception of time centred around the progress of the seasons and months, and then from the age of the industrial societies – when time became an asset having monetary value – the focus shifted to days and the periods within a day. Similarly to spatial orientation, temporal orientation relies on measurements tied to experiences and linked with segmentation.

ORIENTATION IN DAILY AND YEARLY TIME is continuously encouraged in Grades 1–2 and students' knowledge is assessed mainly by having them supply the dates and durations of events. In the topic of CHRONOLOGICAL ORDER OF ENVIRONMENTAL PHENOMENA AND PROCESSES, students' knowledge related to arranging things in chronological order gradually expands over the three age periods. In Grades 1–2, students should identify the chronological order of everyday events (social phenomena) typically associated with certain parts of the day and experienced in their immediate surroundings (Task D13).

Task D13

Arrange the events typical of certain parts of the day in chronological order.

_____ ⇨ _____ ⇨ _____ ⇨ _____ ⇨ _____

A) midday church bell
B) lights out after bedtime story
C) sound signalling the start of classes
D) the ringing of the alarm clock
E) mid-afternoon snack

Surface of the Earth

The learning targets of the topic of the surface of the Earth concern experiential knowledge based on natural curiosity. In order to attain scientific literacy, students should know the properties of the materials making up the surface of the Earth, and the phenomena, changes and principles occurring in the natural environment that created and have been shaping the scene of our existence. At the same time, students should be familiar with the influences of the environment surrounding society and providing the conditions of life for it, so that their thinking and relationship with nature should develop in accordance with the requirements of sustainable development and reasonable safety, and they should acquire environmentally conscious behaviour to protect the resources of the natural environment. An essential component of the study of the surface of the Earth, its phenomena and relationship systems is the use of experimental methods pertinent to different spatial scales: laboratory (sand table and plotting board) observations, field work on educational walks and trips and modelling and simulation with the help of info-communication technologies.

In Grades 1–2, students learn about the properties of MATERIALS OF THE SURFACE OF THE EARTH, e.g., rocks and soil and identify simple landforms (plain, hill, mountain) in real life, in pictures or based on verbal descriptions. They observe the SURFACE SHAPING force of the wind, rivers and precipitation in real life and model these processes on a sand table.

The Hydrosphere and Its Phenomena

Students have abundant everyday experience of the sub-systems of the hydrosphere and the interactions between them. The drinking water running from the tap, the rain dripping from the drain, the groundwater glittering in a hole, the river dividing the town into two all provide a valuable empirical basis for the study of the hydrosphere. The knowledge that can be expected of the students' may be defined at different levels. Regarding its content, it is related to knowledge of the subsystems of the hydrosphere, the principles and phenomena of the water cycle, and the role of water in surface formation. Content knowledge also includes an ability to view water management as a system that lays the foundations of an environmentally conscious life style and contributes to sustainable development.

In Grades 1–2, students learn about the PROPERTIES OF WATER (colour, smell, state), recognise and label different types of water motion in everyday situations (e.g., flow, current, waves, whirlpools). They recognise and compare different types of flowing water and can provide examples for the SURFACE SHAPING EFFECTS OF WATER.

The Atmosphere and Its Phenomena

The physical and chemical properties of the air were first studied relatively late in the history of science. Most of the atmospheric phenomena were, however, known and used in daily life even in the ancient world. At that time, the term meteorology referred to the study of dynamic movements not only near the surface but also in atmospheric 'heights'. Children of the present have a great deal of experience of the properties and changes of state of atmospheric sub-systems, just as they do of the hydrosphere and its phenomena. The natural phenomena most easily observed by students are related to the weather. In this context, it is a basic goal of education to integrate children's spontaneous observations into their system of knowledge and to enable students to apply elements of their knowledge throughout their lives. Since atmospheric phenomena take place in time and space, their study requires spatial and temporal approaches and high-level thinking skills.

In Grades 1–2, students are expected to know about the elements of WEATHER and weather-related phenomena. Tasks include the listing of the properties of air based on experiences in students' immediate living environments and in major geographical areas; the noting, observation and labelling of weather phenomena; the description of weather conditions in students' own words; the identification of seasons based on weather conditions; the noting of changes in the weather and the verbal or pictorial description of the experiences of observation; and the description of experiences of the surface shaping force of the wind.

Knowledge of the Home Locality and of Hungary

The identification of the physical and socio-geographical properties of lands and their relationship systems provides information about whether the students understand the relationship between people and their surroundings, and whether they have developed a sense of national and regional identity, which may also be a basis of understanding and accepting other nations. Being familiar with the location and situation of Hungary in its region, in Europe and in the world plays a role in the emergence of a sense of identity. This also requires solid topographical knowledge. Geographical knowledge is, however, inseparable from knowledge of cultural and historical traditions; it is crucial that students should be familiar with the characteristic features of Hungarian cultural heritage, the historical values of Hungarian culture.

The assessment of knowledge related to the geography of Hungary uses all the task types and assessment methods that were detailed in connection with general geographical topics. The attainable targets expected of the different age groups follow the regional principle proceeding from the known towards the unknown, i.e. from the home environment (Grades 1–2) through the settlement of residence (Grades 3–4) to Hungary and the Carpathian Basin (Grades 5–6). The phenomena, processes and relationships directly observable in the home environment are important for all age groups and students' are mostly expected to be able to apply their knowledge in this context. An important consideration in the planning of content is that the physical elements of geography are linked with human elements, which are important for the development of social knowledge.

The characterisation of landscapes is expected at different levels for the three age groups. In Grades 1–2, it concerns the description of the home environment on the basis of experiences (e.g., What does the surface of the ground in the settlement's surroundings look like? Are there any brooks or rivers? Are there any lakes? How dense is the vegetation in the settlement?).

Our Planet in the Universe

Children have experiences of the appearance of other celestial bodies sooner than they have of the appearance of the Earth. It is therefore useful to explore the historical phases of cultural astronomy: to follow the development of the cosmic worldview and the interpretation of the position of the Earth as a planet in this cosmos. Studies in cognitive psychology suggest that although children have some idea of the spherical shape of the Earth as early as the age of 6, the mental image in their mind is self-contradictory and reflects the conceptions of long-past eras in the history of science. It is difficult for a child (or even for an adult) to integrate the experiences perceived by the sensory organs with the scientific models learnt in the classroom. Although the Earth image in the minds of primary school students contains knowledge-like elements concerning the shape of our planet, when these are compared to sensory experiences, a dual model of the Earth may emerge, which has a spherical shape at an astronomical level and a flat shape at the level of ordinary experiences.

Comprehension requires concordance between verbal knowledge and mental representation. The development of understanding of time and distance on a cosmic scale can be assisted by carefully chosen visual illustrations and the demonstration of research methods used in astronomy.

Diagnostic assessment covers the section of the current scientific model of the universe that is accessible to children of a given age. In Grades 1–2, students may be asked to draw models of our planet as a celestial body in the Solar System; to describe mental models of the shape of the Earth and of the universe; to estimate the proportions of objects relative to the Earth; to distinguish the lands from the oceans at a conceptual level; and to give examples for different types of movement observable in nature.

The Relationship between the Natural Environment and Society

Students have some experience of the challenges of natural forces people must face and are aware that people are capable of securing their living, security and progress even in the midst of varied natural conditions (e.g., the extremities of weather, floods and volcanic eruptions). Knowledge related to the actions of people living in interaction with their natural environment and to the consequences of these actions is a central component of education from the first years of schooling. To be able to understand the relationship between the natural environment and society, students must be able to recognise cause and effect relationships and to handle several types of facts related to spatial interactions that may be in apparent contradiction with each other.

In Grades 1–2, students learn about simple economic activities, occupations and means of transport; they can recognise and name these; and they can compare different methods of travelling and different routes to a destination, e.g., How fast can you travel from home to the school and what means of transport can you use?

State of the Environment

Geographical knowledge forms a complex system in itself. Current earth sciences, however, seek answers to questions related to the description of the geographical environment and its sustainable development and improvement by integrating the results of other areas of natural and social sciences. Geography as a spatial science plays a leading role in the development of a complex approach to environmental science. However, knowledge of biology, physics and chemistry needs to be integrated to understand the issue of nature conservation, and the facts and approaches of social science need to be organised from the perspective of physical geography to understand the issue of environmental protection.

The topic of the state of the environment deals with natural and social resources and problems related to the environment, discusses methods of social co-operation for the alleviation or elimination of these problems, reveals complex cause and effect relationships and opportunities for individual action. Some elements of this complex topic are first mentioned in Grades 1–2. Students can recognise natural, artificial and man-made environments in pictures; know what makes a home environment healthy and what lifestyles are environmentally friendly. They can identify environmental damage in situations in the home environment and distinguish environmentally friendly travelling methods from those causing environmental pollution and biodegradable waste materials from non-biodegradable ones.

The Assessment of Disciplinary Knowledge in Grades 3–4

Non-living Systems

Properties of Objects and Materials, the Discovery of Properties

In this age group, the most important elements of knowledge of MATERIALS include the isolation of the essential properties of bodies and materials, the classification of material properties, the labelling of materials of different states, the description of the different states of matter; the grouping of the materials of the surface of the Earth; and the recognition of the close relationship between the living and the non-living environment. The classification of material properties focuses on a new factor: methods of identifying and testing properties (Task D14).

Task D14

Which properties may be perceived by our senses and which require measurement?

colour roughness denseness electric conductivity smell

The study of materials and their properties mainly involves the examination of solid materials and one typical liquid, water, but it is advisable to extend the concept of matter to include air and other gases as soon as possible. To be able to view air as a material, students must be taught the foundations of knowledge of the structure of matter, but we should take into account that based on their experiences, students envision matter as a continuous structure. The abandonment of the idea of continuity and the acceptance of the particle model is a several-year-long process, which requires a restructuring of knowledge and a conceptual shift. Children limit the concept of gases to the ones known to them from their everyday lives (gas used for heating, exhaust gas) and associate air with 'nothingness', do not see it as matter or gas. As a result, they cannot imagine that air has mass and pressure and it can be heated, etc. At the same time, they have several experiences of air, they link it to winds and breathing, and know that living organisms would perish without it. Relying on students' experiential knowledge of air and gases, observations and experiments may be performed demonstrating a few properties of air, e.g., it can expand, it can be heated, it has mass and pressure (see Task G51) and helping students to accept air as a material.

Familiarity with the properties of gases is also an essential element of being able to distinguish the different STATES OF MATTER. The discovery of the states of matter may rely on children's experience with the three states of water at first but it is advisable to mention the different states of other materials (e.g., metals may be melted, gases may be liquefied). Showing examples can also help children to abandon the common generalisation that every gas is air and every liquid is water.

As the characterisation of gas, liquid and solid states requires the differentiation and elementary interpretation of several concepts (e.g., volume, shape, particle, motion, and force), physical states are characterised at different levels in the various age groups. In Grades 3–4, students may be expected to group materials according their state (Task D15) or to describe states of matter in simple terms.

Task D15

Sort the materials found in a house into groups.

paper glass air oil china milk aluminum

Gas	Liquid	Solid

The exploration of measurable physical properties involves the measuring of length, mass, temperature and volume (first for fluids, then for solids and gases using the displacement method), and teaches students to use simple measurement devices. Students become familiar with the concept of measurement (measurement involves the comparison of a physical quantity with a unit of measurement); explore the relationship between estimation and measurement; learn to differentiate between the concepts of quantity, unit of measurement and numerical value of measurement; discover the relationship between different units of measurement; and learn to use simple measuring instruments, to read scales and to use different weights when measuring mass. At this stage, we may prepare the ground for the future introduction of the concept of density by discussing everyday phenomena that are based on differences in density between materials (e.g., oil or ice floating on the surface of water).

Changes in Materials: Changes of State, Mixing, Dissolution and Combustion

In Grades 3–4, students may be expected not only to label changes of state observable in everyday life but also to identify the causes effecting the change (e.g., melting, evaporation and boiling are caused by heating, and freezing and condensation are caused by cooling) (Task D16).

Task D16

What change of state can you identify in the phenomena given below?

The grass gets wet with dew.
The clothes hung on the washing line get dry.
The icicle is dripping.

It has been frequently observed that students do not consider matter to persist during phase transitions (e.g., liquid water and ice are different materials; water vapour is actually air), tend to disregard the conservation of matter and energy (e.g., when ice melts, its mass decreases), and equate the three states with water. It is therefore important that besides showing the changes of state of water, we should also indicate that given the right conditions, almost every material may be manifested in all three states.

At this age, the development of the concept of MIXTURE, the ability to distinguish and characterise component parts and to identify the methods suitable for separating ingredients (Task D17) may be assisted through the examination of macro-level mixtures found in the environment or in the home, e.g., sand and pebbles, sand and water, cereals with dried fruit, cocoa powder with sugar or a stock cube.

Task D17

How can the following mixtures be separated into their components?

sandy water   pebbles in sand   salt water   sweetened cocoa powder

Task D18 evaluates the identification of the properties of macro-level mixtures, and may be modified to include submicro-level or particle-level mixtures in Grades 5–6 (e.g., listing of the preserved and altered properties of the components of lemonade made of sugar, lemon and water).

Task D18

We mix sand with water. Which of their properties do sand and water preserve in this mixture?

The next level of children's understanding of DISSOLUTION is when they start using expressions describing the changes in the solute when they give an explanation for the dissolution of sugar or salt in water: "it is destroyed, it breaks into pieces, it melts". These expressions reflect ideas associated with the image of matter as something constant. The use of the word 'melt' continues to persist – mostly as a consequence of its everyday usage – even when the student is able to interpret the process of dissolution at the level of particles. An example demonstrating the difference between dissolution and melting is the dissolution of sugar in water contrasted with the melting of sugar, which shows that while dissolution is the result of an interaction between two substances, melting involves a change of state in a material caused by heating. Students' understanding of the difference between dissolution and melting may be evaluated by a truth value judgement task, for instance (Task D19).

Task D19

We put two teaspoons of sugar in a mug of tea then mix it. What happens? Which of the statements are true and which are false? Justify your answer.

The sugar melts in the tea.
The sugar is mixed in the tea.
The sugar disappears in the tea.
The sugar can be recovered from the tea.

The experience that for solid substances, more of them can be dissolved in warm water than in cold water is often associated with melting by children: "the hot water melts the sugar". The first sign of the appearance of a particle-based interpretation is the description, "it breaks down to invisible pieces". About a quarter of children in Grades 4−6, and a third of students in Grades 7–8 use a particle-level interpretation in explaining the dissolution of sugar in water. It is important to realise, however, that when students talk about particles, they think of small pieces of the solid substance rather than of the chemical particles it is composed of (ions, molecules).

The combination of the everyday idea of continuous matter and the particle model may give rise to the following synthetic models: (1) Particles can be found in the continuous matter ("the substance that makes sugar sweet has been released from it"); (2) particles have macroscopic properties ("sugar melts and its particles are sweet", there are sweet atoms in it, "the particles of the sugar became liquid").

Due to the complex nature of the concept, it is very difficult to understand and interpret correctly the process of COMBUSTION even though students have plenty of experience of this phenomenon. They are familiar with combustible substances in their environment, can give examples for the uses and dangers of burning and know the essential actions they must take in case of fire including the basic rules of raising an alarm, escaping and extinguishing a fire. In the beginning, students tend to rely on three types of model for the interpretation of combustion. (1) According to one of the models, the combustion of solid substances (wood, candle, magnesium) is interpreted as a change of physical state. (b) The transmutation model contends that the process of burning transforms a 'non-combustible' material (e.g., magnesium) into a known 'combustible' material (e.g., carbon), the burning of which is compatible with everyday experiences. (c) According to the theory of 'adhesion' a combustible material is composed of a number of components, which are glued together in the beginning and simply come apart during combustion. That is, combustion is not the interaction of materials but the separation of attached components. Research studies indicate that some students in Grade 9 still interpret the combustion of magnesium in terms of a similar model.

One major problem is that the oxygen needed for combustion is invisible, which makes it difficult to view as a substance (the oxidising agent) participating in a chemical reaction. Children's interpretations of combustion may include models very similar to the phlogiston theory. According to the phlogiston theory, all combustible materials contain an element that is released during the course of burning, which explains the decrease in the mass of the substance burnt. This element is named phlogiston. The more phlogiston is contained in a substance, the better it burns.

In addition to the problems discussed above related mainly to teenagers' interpretation of concepts, there is an increased risk of comprehension problems arising from the difficulties of the categorisation of concepts among younger students. Some children, for instance, consider heat and energy to be substances and fail to distinguish the process of heating from the concept of heat. It is therefore important to include tasks testing students' ability to differentiate between heating and burning in diagnostic assessments (Task D20).

Task D20

Explain the differences between heating and combustion. Give an example of both processes.

Interactions

In this age, students learn about electric, magnetic and thermal interactions in addition to mechanical interactions. It is just as important as before to provide examples assisting students' understanding of the fact that participants undergo changes in interactions and their changes are complementary. We should also discuss the cause of changes (e.g., a broken window – a child playing with a ball, a withered plant – lack of water) and the attributes that change (e.g., the length of a spring changes when it is stretched, or the mass of a seed changes when it germinates).

The motion of bodies and changes in their state of motion are the interactions posing the greatest challenge because the prior knowledge of students is difficult to reconcile with scientific knowledge. Children interpret the motion of bodies in terms of Aristotelian physics: Motion always has a cause, and when there is no force maintaining motion, the body stops moving. This view is fundamentally different from Newtonian physics: Motion does not stop spontaneously, bodies left alone in an inertial reference frame are at rest or move in a straight line at a constant speed; that is, the motion of bodies is not caused by an external force, the external force is required to change the state of motion. There are several tests to detect the persistence of the Aristotelian model (e.g., Why does a rolling ball stop after a while?). Children's answers often express the idea that "the ball has run out of power", indicating that force is considered to be a property of the body; it is not associated with the interaction and is not seen as the force causing the change of the state of motion.

Energy

In Grades 3–4, students knowledge of energy can be extended to cover the classification and characterisation of fuels and other energy resources and the uses of electricity; the recognition of the relationship between work and changes in energy; and a discussion of the roles of heat and light in the natural environment. Students also learn about the problem of depleting the supply of energy resources and raw materials, and about the importance of the economical use of non-renewable sources of energy. Students should be able to decide which of a set of materials are combustible; to list fuels; to know that food is a source of energy for living organisms. In Grades 5–6, sources of energy are discussed in greater detail, non-renewable and renewable energy resources are distinguished and the relationship between energy production and environmental pollution is discussed.

Students may be prepared for understanding the flow of energy by analyzing the flow of light, sound and heat and by discussing naive conceptions of light, sound and heat. At the beginning of this period, the majority of students do not consider light to be an independent entity but equate it with the source of light and fail to associate it with motion. Most students also fail to establish a connection between light and vision. According to our studies, only a low percentage of Grade 5 students know that we see objects because the light reflected by their surface enters our eyes. Most of them think that we see objects because there is daylight and the light illuminates them. The understanding of the spreading of sound only becomes possible when students start regarding air as matter, a system consisting of a great number of particles.

Living systems

Criteria of Live, Properties of Living Organisms

In Grades 3–4, breathing and circulation are added to the set of life processes known to the students and their concept of life becomes more sophisticated. Students of this age still tend to chose one of the life processes (usually motion, feeding, breathing, reproduction, sensitivity, and occasionally growth and death) as the most important factors differentiating living and non-living things. They also tend to use everyday words in their descriptions, such as ‘eat and drink’ instead of ‘feed’, and ‘feel and sense’ instead of ‘sensitivity’. Towards the end of this age period, we can look at the interpretation of motion as a distinguishing feature (Task D21).

Task D21

When we pour petrol in the car (‘feed it’) and start it, it will move but it is not a living thing. Explain why.

Unicellular Organisms

Given its proportions, microscopic life is unimaginable for a child in the period of concrete thinking. It becomes real only when it appears as a visual image and the child can see for him or herself life existing at a cellular level. Familiarity with the proportions and units of measurement is an essential precondition of the understanding of unicellular organisms. Due to the absence of this knowledge and to difficulties with the complex, fine motor movements needed to handle a microscope, it is unreasonable to study microscopic life in Grades 1–2.

In Grades 3–4, when students are familiar with the units of length measurement and know how to use them and when they are capable of handling a microscope, it is worth showing them the simplest and most easily analyzable unicellular organisms (e.g., paramecium, giant amoeba, Euglena viridis). Based on the samples, students can identify the basic differences between the body structures of unicellular and multicellular organisms.

Body Structure, Classification, Life Processes and Living Conditions of Plants

In this age group, in addition to the observation and description of plants, the effects of environmental conditions are studied. For the first time, the characterisation of plants includes the concepts of flower, fruit and pollination and different types of herbaceous plants are distinguished. Getting to know the structure of a complete flower (without the details of the ovary) goes beyond the students' experiences and thus scientific concepts are gradually introduced. Students become familiar with a new ecosystem, the plants of a meadow, and characterise these plants with the help of newly acquired botanical concepts. Students learn the taxonomic classification of species but the taxonomic categories (phylum, class, etc.) are not labelled.

In Grades 3–4, the set of life processes of plants is expanded to include functions such as nutrition, breathing and circulation of nutrients. Plants and animals can now be distinguished by the introduction of the concept of locomotion. The linking of individual life processes with individual plant organs serves as a demonstration of the relationship between structure and function (Task D22).

Task D22

Link the parts of a plant with their functions.

roots	Fruit develops from it.
stem	It holds the plant parts above ground and transports nutrients.
leaf	It holds the plant in place.
flower	It absorbs water and the minerals dissolved in it.
	It makes food.

Body Structure, Classification, Life Processes and Living Conditions of Animals

In Grades 3–4, water and waterside appear among the habitats discussed. Animals are explored by taxonomic groups and are characterised through familiar morphological concepts (Task D23). Several new concepts are also introduced, e.g., herbivore, carnivore, omnivore; constant and variable body temperature; types of reproduction and development: with or without metamorphosis (Task D24).

Task D23

Describe the groups of animals according to the given criteria.

Criteria	Crustaceans	Insects	Spiders
Body regions			
Number of legs			
Type of development			without metamorphosis

Task D24

Put the developmental stages in order by numbering the pictures. Name the type of development.

A) 

B) 

In addition to identifying the shared morphological properties of individual groups of animals, children should also be able to name the organs of feeding, breathing, movement, reproduction and the outer cover of the body and understand the relationship between their characteristics and the animal's life style. They learn that the structure and functioning of the animal's body is influenced by the environment. Their characterisation of different species refers not only to their morphological and taxonomic properties but also to their life styles. Diagnostic assessment tasks may involve the characterisation of different groups or species of animals or the identification of animals based on a set of characteristics (Task D25).

Task D25.

Who am I?

> I live in the forest, and I am a carnivorous mammal. My hearing and my sense of smell are excellent. I go hunting at dusk.
>
> I have 3 pairs of jointed legs. I collect nectar and pollen flying from flower to flower with my membranous wings and I make honey from them.

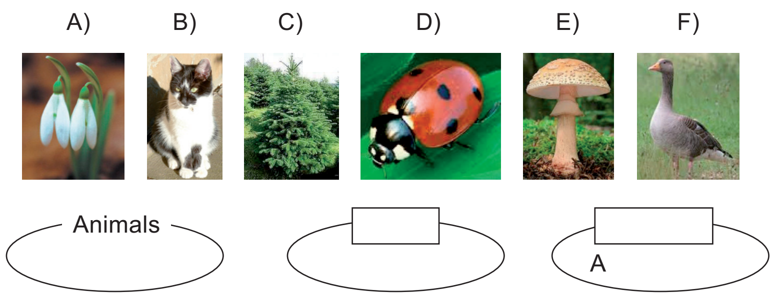
Students in this age group can learn that every group of animals has a specific role in life on Earth. This process can be encouraged by asking students to think of examples for links between the kingdom of plants and that of animals and for their interdependence, and by carrying out guided observations.

Structure and Classification of Fungi

In Grades 3–4, discussion of fungi still centres around mushrooms. Students observe the similarities and differences between them, and learn the rules of mushroom consumption. A common error persisting at this age is that students count fungi among plants (Task D26).

Task D26

Complete the grouping of the life forms.



Body Structure, Life Processes and Health of Humans

In Grades 3–4, students acquire more detailed knowledge of the structure and life processes of the human body and the relationships between them: the parts of the gastrointestinal tract, the major organs of the digestive system and their functions; why we need food and what happens to the food consumed; the main classes of nutrients and their functions. Students learn the parts and functions of the respiratory tract (Task D27);

the process of inhalation and exhalation; the stages of human life and their characteristics (Task D28); and the environmental conditions essential for human beings.

Task D27

Put a circle around the names of respiratory organs.

lungs chest nasal cavity
oesophagus windpipe

Mark the passage of air with an arrow.
How does oxygen get to every part of the body?

Task D28

When you look through a family photo album, you can follow how people change over the years. Estimate the age of the people described by the following statements.

My little brother slept through most of the day at that time.

This picture was taken of me in Grade 1 with my favourite book.

Some pimples appeared on my sister's face.

The topic of HUMAN HEALTH describes the differences between a healthy and a sick organism, the symptoms and causes of a few diseases, the distinction between communicable and non-communicable diseases and the role of vaccines. Students learn that a healthy diet is part of a healthy lifestyle; discover the relationship between the consumption of food and water, physical activity and health; and recognise the dangers of harmful substances and habits.

Ecosystems

In Grades 3–4, students explore different types of ecosystems (forests, meadows, water and watersides) and their characteristics (spatial structure, location), and learn the elementary concept of ecosystem and the biosphere. A greater emphasis is placed on the network of feeding relations (Task D29) and on the effects of environmental changes, e.g., the seasons on ecosystems.

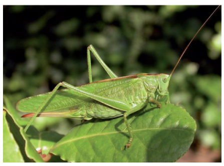
Task D29

Construct a three-element food chain from the organisms below.

western marsh-harrier

grasses

brown hare



great green bush-cricket

common vole

sand lisard

___________ ⇨ ______________ ⇨ ___________

Environmental Protection, Conservation of Nature

In Grades 3–4, students become familiar with some fundamental concepts of environmental studies (e.g., waste), and they learn the concept and practice of waste recycling. There is increasingly more discussion of the ways mankind may cause harm to nature and the environment and of appropriate behaviours avoiding such harm.

The Earth and the Universe

Orientation in Space

While in Grades 1–2 activities related to orientation in space are based on direct observation, the activities in Grades 3–4 involve objective comparisons and more complex methods of inquiry (e.g., experiments, identifying cardinal directions). When REPRESENTING REAL-WORLD SPACE, directions are no longer the only relative concepts but the sizes of objects are also compared and represented on maps or plans of different scales, generally limited to familiar spaces (for instance, drawing the plan of a room based on a description of the pieces of furniture). The assessment of ORIENTATION IN SPACE focuses on the graphical representation of information provided for the students and on the identification of topographic concepts represented on simple maps of the students' home environment and its surroundings. Students' knowledge of the ELEMENTS OF SPATIAL STRUCTURE AND THEIR HIERARCHY is assessed through tasks requiring measurement along a straight line on a map or plan and the calculation of distances based on the scale of the map. Students in Grades 3–4 can discover that there are events and processes in our environment that follow distinct spatial arrangements. This knowledge can be tested using a task, for instance, where looking at the picture of a landscape, students need to identify natural phenomena, e.g., the sun shining, the stream running and social phenomena, e.g., wheat being harvested or children cycling, and to put them in order when going for an imaginary walk along a given route.

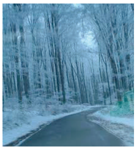
Orientation in Time

In Grades 3–4, students continue to improve their orientation in DAILY AND YEARLY TIME. Tasks assessing orientation in time involve the identification of the time or date and the duration of various events and phenomena. The assessment of students' knowledge of the TEMPORAL ORDER OF ENVIRONMENTAL PROCESSES (Task D30), and of socio-economic activities (Task D31) uses events naturally associated with seasons.

Task D30

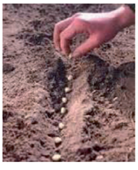
The pictures below were taken in the same year. Arrange the pictures in chronological order.



Task D31

Which part of the year are the following activities associated with? Put the pictures in chronological order.




Surface of the Earth

In Grades 3–4, students learn about the properties of the MATERIALS OF THE SURFACE OF THE EARTH. They can identify minerals and rocks, compare different types of soil, name soil constituents (weathered bedrock, organic fossils, water, air), choose the appropriate tools for examining rocks and minerals and perform simple experiments. Students also become familiar with a wider range of LANDFORMS. They recognise plains, hilly and mountainous landscapes in pictures, models or from descriptions and learn to model them on a sand table. They can list the parts of simple landforms, e.g., a hill or mountain's side, slope, foot, top, peak or ridge. They can identify the internal and external forces shaping surfaces and recognise their effects (weathering, lowering, elevation) in given examples.

The Hydrosphere and Its Phenomena

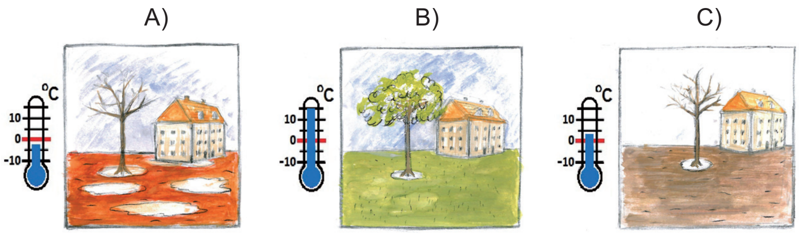
Children have several kinds of everyday experiences of water. It is important to supplement this knowledge with a purposeful examination of the PROPERTIES OF WATER and the verbal description and recording of experiences. Experiments with water can be performed with assistance in Grades 3–4. The assessment of students' knowledge of the properties and uses of water can cover simple procedures of water purification, the subprocesses of the water cycle and changes of state of water with demonstrative examples; the interpretation of the importance of water in daily life, the identification of objects of flood prevention and river bank protection in pictures or diagrams. In connection with the topic of SURFACE SHAPING WATER, students can be required to group types of water by their location, to explain the movement of water, describe the hierarchy of flowing water, identify and name an estuary and distinguish still water from flowing water.

The Atmosphere and Its Phenomena

In Grades 3–4, just as in the previous period, the knowledge students are expected to attain concerns the ELEMENTS AND EVENTS OF WEATHER, and the concept of climate is not formed until Grades 5–6. Until students have firm understanding of the elements of weather, the abstract concept of climate cannot be developed. The acquisition of knowledge related to weather presupposes the recognition of the presence and significance of air and familiarity with its properties. In Grades 3–4, in addition to observing the elements of weather, students also carry out measurements, e.g., the measurement of temperature, record and analyse their data and draw conclusions from the data with regard to the elements of weather. In Task D32, for instance, students need to extract the data from the diagram and draw conclusions as to the type of precipitation based on the data.

Task D32

Complete this table according to the weather conditions illustrated in the pictures.



	A)	B)	C)
The name of the precipitation expected			
The state of the expected precipitation			
Air temperature			

Knowledge of the Home Locality and of Hungary

In Grades 3–4, students are able to give a geographical description of the area they live in, to name objects belonging to the social environment of their area (transport network, residential and industrial buildings, public institutions) and to list the natural and social resources of the area where they live. The description of this environment is based on a set of prespecified attributes and proceeds from the immediate home to the settlement surrounding the home (Task D33).

Task D33

Introduce your home area using the following topics.

terrain and surface
typical weather
rivers and still waters
vegetation
buildings and structures
economy

Our Planet in the Universe

In Grades 3–4, students continue to refine their conceptions of the shape of the Earth. We can analyse students' explanations of what makes the Earth spherical and ask students to compare different sizes and distances, (e.g., Which is further away, the Moon or the Sun?). In connection with the topic of the REGIONS OF OUR PLANET, students become familiar with lands and oceans and learn to recognise and name them on a simplified map. In connection with the STRUCTURE OF THE UNIVERSE, students learn to recognise celestial bodies in the Solar System and various phenomena in the universe based on pictures and examples; they can compare and model movement with change of location and motion with change of position, and interpret the role of the daily passage of the Sun in their personal lives.

The Relationship between the Natural Environment and Society

In Grades 3–4, students learn about further economic activities and group them according to economic sector. They become familiar with several ways of saving energy; analyse the advantages and disadvantages of various means of transport in terms of different considerations, e.g., journey time, timetable constraints or environmental pollution; and plan a journey using timetables. Students of this age can be expected to be able to interpret relatively simple, printed timetables used mainly in urban public transport systems.

State of the Environment

In Grades 3–4, students can identify substances and processes harmful to the environment; and recognise methods of managing natural resources in examples. They are familiar with the purpose of recycling, the concepts of protected natural resources and environmental protection and with environmentally responsible behaviour.

The Assessment of Disciplinary Knowledge in Grades 5–6

Non-Living Systems

Properties of Objects and Materials, the Discovery of Properties

This is the period when the foundations are laid for the study of the structure of materials at the level of particles. The macroscopic properties MATERIALS are distinguished from the properties of particles and the different states of matter are compared based on knowledge of the particle model. The development of students' cognitive abilities now enables them to distinguish the concepts of mass and density, to learn about further properties of materials, e.g., mechanical, electric and magnetic properties and heat conductivity, and expand their knowledge of the properties of materials and objects (Task D34). Students categorise the materials of the surface of the earth on the basis of more detailed principles; study the properties of utilisable rocks, minerals and energy resources; can identify materials harmful to the environment or dangerous for humans; and list examples for the cycling of substances in nature.

Task D34

Which of the properties listed below are the properties of materials and which are the properties of objects?

elastic flexible long good insulator of heat combustible
has a great mass has a low density magnetisable

Properties of materials	Properties of objects

The development of students' concept of gases can be encouraged with the help of ball-and-stick models, which can illustrate the uniform distribution of gas particles in an enclosed space, the empty space between the particles, the motion of the gas particles, and the creation of gas mixtures. The introduction of the ball-and-stick model is the first step towards students' understanding of the relationship between the structure and properties of materials and of the facts that particles cannot be perceived by the naked eye or through an optical microscope and do not have macroscopic material properties, e.g., colour, smell or hardness. Students of this age often combine their continuous material conception with the particle model (e.g., particles are pieces of matter, which is continuous; there is some filler material between the particles: air or pollution; particles have the properties that characterise the material: compressibility, colour, hardness, ability to get warm or cool).

Initially, students believe that the particles of solid materials are unordered, and it is only in Grade 8 or so that they begin to understand the idea of ordered structure and the interactions between the particles. The structure of liquids is the most difficult to conceptualise for students. They consider the particles of a liquid to be minute drops, and the motion of the particles and the connections between them are difficult to interpret. That is why students have problems analysing the process of dissolution at the level of particles.

Students' uses of the particle model, and whether it is used at all, can be assessed by asking them to explain some everyday processes. For instance, Why is it that we can smell the dinner being cooked in the kitchen in the room? Why can we squash a balloon filled with air? Why do solid bodies maintain their shape?

The development of the concept of DENSITY starts with the observation of the phenomena of swimming, floating and sinking and the differentiation of mass and density. It is important to discuss that the concept of density as used in everyday life, which is mainly related to viscosity in Hungarian (e.g., custard may be dense or runny) is not equivalent to the physical concept of density. An added difficulty with the accurate use of the concept of density is that both the property of the material and the quantity characterising it are labelled with the word density in physics. To be able to understand the concept of density as a material property, students must be able to use an elementary particle model; and the understanding of density as a derived quantity requires the recognition of the relationship between two quantities (mass and volume). Tasks asking for the comparison of quantities with the use of a density table (e.g., Which one has larger volume: 1 kg of oil or 1 kg of pine-wood? If given a piece of wood and a piece of iron of the same volume, which one has greater mass?) may also be used for practice and measurement. The realisation that mass is a property of objects while density is a property of materials is a major step in the development of the concept of density. The concept of mean density may also be introduced with the help of the experiences of experiments, and students' understanding of the concept may then be assessed by asking students to give explanations in their own words (e.g., Why does a glass bottle float on the surface of water and why does solid glass sink?).

Students' also examine electric conductivity, magnetic properties and thermal conductivity. MEASUREMENT is used not only to determine various quantities but also to find out which quantities are added together in an operation (e.g., mass when two liquids are mixed, and also volume if the liquids are identical) and which quantities come to equilibrium (e.g., temperature, density). In this age group, the range of measuring instruments, experimental tools and technical tools, e.g., optical and electric tools known to the students also becomes wider.

Changes in Materials: Change of State, Mixing, Dissolution, Combustion, Decay

CHANGES OF STATE are interpreted with the help of an elementary particle model. Having a concept of particles helps students to understand the difference between dissolution and melting and to distinguish reversible from non-reversible processes. In this age group, the study of changes of state includes the observation and measurement of changes in temperature, mass and volume. Students learn the concept of melting point and try to explain why there is no rise in temperature as a result of steady heating while ice is melting. The consequences of the difference in density between water and ice and the expansion of the volume of ice can be demonstrated by several everyday examples (e.g., freezing of water pipes, frost damage in roads), and may be linked to what has been learnt on the formation of landforms (e.g., the weathering of rocks).

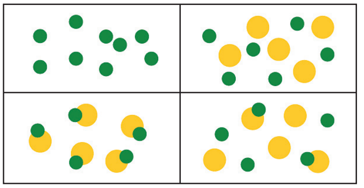
The study of MIXTURES now includes mixtures of particles, e.g., solutions, and students in these grades start interpreting the process of mixing at the level of particles. The comparison of the properties of macro- and submicro-level mixtures can prepare students for the differentiation of homogenous and heterogeneous mixtures in higher grades (Task D35). Students' understanding of the distinction between pure substances and mixtures at the level of particles may be assessed using Task D36.

Task D35

We mix sand with water and in another dish we dissolve salt in water. Compare the properties of sandy water and salt water.

Task D36

Which particle diagram depicts a pure substance and which depicts a mixture?



In this age group, students' explanations of SOLUTIONS are more likely to use the concept of particles. Although their wording tends to be quite inaccurate, the explanations indicate understanding of the idea of dissolution: "the rapidly moving water molecules break the bonds of the sugar", "the sugar is broken down to molecules as a result of moisture".

It is apparent in their interpretation of the process of dissolution that children distinguish between the materials participating in the various changes and identify active and passive participants. In a process of dissolution, the active substance is the solvent and the passive substance is the solute. "The solvent dissolves the solute." "The solute undergoes changes during dissolution but the solvent does not." Unlike children in Grades 1–4, students in Grades 5–6 may be ready to draw a distinction between the extent and the speed of dissolution. It is worth keeping in mind that everyday language uses the expression 'it dissolves well' both for the description of the extent of solubility (a lot of it is dissolved) and for the speed of dissolution (it dissolves quickly). The misconception that the extent of dissolution (also) may be increased by stirring may persist even in college students. With the assistance of their teachers, students in Grades 5–6 can learn that when we sweeten the tea, for instance, stirring increases the speed of dissolution and not the degree of solubility. The effects of temperature are even more complicated. An increase in temperature clearly increases the speed of dissolution but in general it only increases solubility in the case of solid substances, while in the case of gases it decreases it. In this context we may mention fish gulping for air on a hot summer day because the amount of oxygen dissolved in the water has decreased.

In this age group, we may expect students to regard not only water but also alcohol and petrol as solvents. We may mention alcoholic extracts (tinctures) or the additives dissolved in petrol. It is also important to note that not only solids but also gases or liquids may be dissolved. We may assess students' knowledge of the components of a solution with Task D37, for instance.

Task D37

Name some everyday solutions in which …

the solvent is water and the solute is a solid.
the solvent is water the solute is a gas.
the solvent is not water.

We may perform several simple experiments with the students in connection with the topic of dissolution, mainly involving the dissolution of salt or sugar in water. We can assist students' understanding of dissolution by using coloured solutes (e.g., bluestone). Since students have everyday experiences related to dissolution, they can be asked before performing the experiment what they expect to happen. Students' ability to differentiate between the extent of solubility and the speed of dissolution may be assessed with Tasks D38 and D39.

Task D38

There is 200 ml of tea in each of two cups of the same size. We put one teaspoon of sugar in each cup then we stir the contents of one cup with a spoon and leave the other cup on the table. Compare the extent and speed of dissolution of the sugar in the two cups.

Task D39

There is 200 ml of tea of a given temperature in each of two cups of the same size and shape. We put 2 g of sugar cube in one cup and 2 g of granulated sugar in the other. In which cup will the sugar dissolve more quickly? Add a relation symbol between the two cups. Justify your answer.

As was shown in connection with the previous age group, students interpret the concept of COMBUSTION in a variety of ways. The development of the concept has the following major stages: (1) Combustion is always accompanied by a decrease in mass. (2) Combustion requires air (oxygen). (3) Combustion may be accompanied by an increase in mass.

(4) Combustion is possible with substances other than oxygen. Several studies have demonstrated that the development of the correct concept of combustion requires sufficient knowledge and appropriate application of the particle model. Diagnostic assessments may test students' ability to distinguish between rapid and slow combustion (Task D40), to interpret combustion and to understand the conditions of burning (Tasks D41 and D42).

Task D40

Group the combustion processes taking place in the situations given below.

match smouldering   wood decaying   coal glowing   iron gate corroding

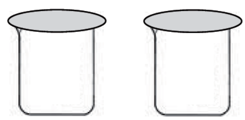
slow combustion: ....   rapid combustion: ....

Task D41

We put a candle of equal mass in each pan of the balance scales. If we light one of the candles, the arms of the scales will move. In which direction will the arms move? Justify your answer.

Task D42

There is carbon-dioxide in one dish and oxygen in another. We insert a sparkling igniting stick in both dishes. What happens to the sparkling igniting sticks? Justify your answer.



The DECAY OF MATERIALS is aptly illustrated by the common phenomenon of transformation of food substances during storage or utilisation. This transformation may be accelerated by increasing the temperature and it may be decelerated by decreasing the temperature or by adding preservatives. When teaching this topic, we may make use of students' everyday experiences and highlight some practical pieces of knowledge (e.g., best before date, the use of the refrigerator and the heating devices in the kitchen, the meaning of E numbers). We may note the parallel with the temperature dependence of the speed of other processes (mixing and dissolution) and when the causes of decay are discussed, we may create links with topics in biology, e.g., bacteria and fungi.

Interactions

When motion and changes in states of motion are discussed, the concept of force should be linked to the concept of momentum, which has a natural presence in children's minds, and later on force should be referred to as something that changes the momentum of the body (Task D43).

Task D43

Does a fast or a slow football hit something harder?
Explain why.

Students are able to answer the above question based on their experiences but they can only provide an explanation at the end of this age period, when they can connect the concept of momentum with state of motion, and the concept of force with a change in state of motion. The development of the concept of force may be problematic since force and energy are often fused in everyday language (e.g., industrial facilities that generate energy are called power plants), and it is therefore important to assist the differentiation of the two concepts and their correct use starting with lower primary education.

The study of gravitational interaction may be introduced by a discussion of everyday experiences. For example, an object dropped accelerates as it is falling, a ball decelerates when thrown up in the air, it stops for a moment and then falls back down with an increasing speed. The speed of a body changes during a fall, which indicates that it is acted upon by some force. Children's understanding of gravitational interaction is hindered by the common misconception in their minds that objects fall downwards (as if there were an absolute vertical direction) rather than towards the centre of the Earth. The development of the concept of gravitational force and the acceptance of its direction is a long process. This is the reason why students are initially unable to explain why people and objects do not fall off the sphere of Earth, and what keeps oceans in place. A major step in the understanding of gravitational interaction is the realisation that not only Earth but every body has a gravitational field, which explains the motion of celestial bodies. It is important to draw students' attention to the fact that the force of the gravitational pull is perceptible to an observer only if one of the bodies' mass is very large (e.g., one of the bodies is a celestial body). The pull between the Earth and the ball is easy to perceive, while the pull between two balls may be detected only with sensitive instruments.

Energy

In Grades 5–6, energy resources are studied in more detail, a distinction is made between renewable and non-renewable resources and the relationships between energy production and environmental pollution are discussed. Students are able to interpret the concept of energy dependence of various human activities; they can give examples for methods of producing energy and identify the relationship between the various methods of energy generation and the natural environment. They are familiar with examples of renewable and non-renewable sources of energy and know that the energy needs of a living organism can be satisfied by nutrition; people also use external sources of energy, e.g., fossil fuels in their daily activities; and virtually all sources of energy used by people ultimately originate in energy from the Sun.

As children are beginning to form an elementary particle image of matter, they are able to use a ball-and-stick model and visualise light as matter (in light, extremely small balls fly about with enormous speed) and sound as vibration transmitted from particle to particle in the air. Students are now ready to analyse the changes caused by interactions and link energy decrease to one and energy increase to the other participant in the interaction (e.g., hot tea cools – energy decrease, its environment warms – energy increase); to differentiate between the concepts of heat and temperature, and to treat heat as a quantity tending to equilibrium (e.g., the explanation for the settling of temperature at an intermediate point between hot and cold water).

Living Systems

Criteria of Life, Properties of Living Organisms

In Grades 5–6, further differences are discussed between living beings and non-living objects: cell structure, adaptation to the environment and participation in ecosystems. Students of this age are not ready to understand the abstract, general concept of life. An important step in the development of the concept of life is when the structural and functional properties of living organisms and the links between them are discovered. The body structures and life processes of living organisms and changes in these (adaptation to the environment) are a major component of the school subject of nature studies. With the help of examples, students are able to understand that no living being can exist without the non-living environment; the living and the non-living environment are dependent on each other and affect each other in various ways. They are familiar with environmental factors affecting the existence of life forms (water, soil, air, light, temperature), and relying on a few concrete examples they also know that the significance of individual factors varies across different plants, e.g., we do not need soil to grow tomatoes as they can be grown in a potting mix. Task D44 may be used towards the end of the period or in higher grades.

Task D44

Look at the following sets of environmental factors and select the one that every living organism needs.

air and water
light and appropriate temperature
appropriate temperature and water
soil, water and light
water and soil

Unicellular Organisms

In Grades 5–6, unicellular organisms are characterised in terms of the relationship between the environment and lifestyle and they are positioned in the taxonomy of life forms. Students are aware of the basic differences between unicellular and multicellular organisms, and can develop a concept of cells based on the structural and functional properties shared by unicellular organisms. The differences between the individual cells of a multicellular organism and the single cell of a unicellular organism are not discussed until higher grades, however.

Body Structure, Classification, Life Processes and Living Conditions of Plants

Grades 5–6 are accompanied by a major qualitative change in the cognitive development of children, which is reflected in the level of abstraction accessible to students in the study of plants. New scientific concepts of plant biology are introduced, e.g., angiosperms, gymnosperms, seeds, sepals, carpel and stamen, perigone, hermaphrodite, monoecious and diecious plants, fruit, pollination, inflorescence, root systems, primary and secondary roots, shoots, rhizome, compound leaves, leaf veins, feather and parallel-veined leaves, cotyledons, monocotyledons and dicotyledons, budlets and radicles, which allow students to describe the external features of plants in considerable detail. In these grades, plants are not described at the level of tissues or cells.

The plants of the various ecosystems are studied with reference to taxonomic categories and structural and taxonomic concepts. The description of plants proceeds from the whole plant to its parts. Their taxonomic and structural description (Task D45) is supplemented by the discussion of their roles in the environment and in food chains and by the identification of their functions in everyday life, agriculture and industry. Students of this age are capable of understanding the interrelationships between the various taxonomic groups, e.g., angiosperms and gymnosperms, monocotyledons and dicotyledons (Task D46), identifying the properties shared by the plants in a given taxonomic category and, conversely, identifying the taxonomic category when given a list of common properties (Task D47).

Task D45

Which plants have the following properties?


scotch pine

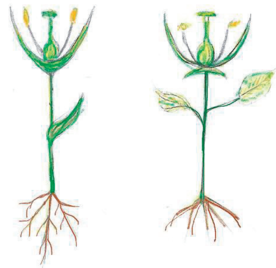

blackthorn


snowdrop

It has thorns.
It has a drupe.
It has a bulb.
It has cones.
It is evergreen.

Task D46

Which organs need to be swapped to have a monocotyledon and a dicotyledon in the pictures?



monocotyledon dicotyledon

Task D47

Which group of plants do you recognise from the statements below?

They do not have flowers, they reproduce with spores and have simple roots, stems and leaves.

They are flowering plants, they reproduce with seeds and do not have fuits.

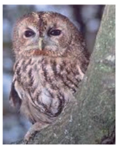
In Grades 5–6, the concept of photosynthesis is introduced at an elementary level: plants produce food from nutrients absorbed from the soil and the air using energy from sunlight. The discussion of the topic focuses on the relationships and interactions between biological processes in plants and the environment. Studies have shown that of the conditions of life of plants (water, air, soil, light and temperature) water is the first to be identified by students. This can be explained by the fact that children tend to rely on their own experiences as a starting point and they know from experience that plants need to be watered or they will wither and die; that is, plants need water. The condition of plant life most difficult for children to identify is the correct temperature, which is known by only about half of students in Grade 6. Some of the students are able to distinguish the non-living factors that are important for every living organisms from the ones that have varied levels of importance across life forms.

Body Structure, Classification, Life Processes and Living Conditions of Animals

In Grades 5–6, the study of the properties animals – just as the study of plants – focuses on body structure, life processes, lifestyle and the environment. Students learn about organs having an important role in the definitions of major taxonomic categories (e.g., spine). The morphological description of animals and groups of animals is based on their life processes (nutrition, breathing, reproduction, motion and outer cover). The set of species and animal groups discussed does not grow significantly relative to the previous period but the habitats and the animals are studied in a more systematic way (Task D48). The role of the given species of animal in the living world, in the environment and in daily life is added as a new criterion of description.

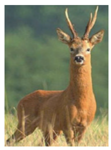
Task D48

Group the animals according to their habitat.

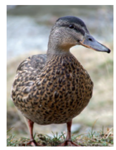


tawny owl

edible frog



roe deer



mallard

wild hog

Forest: .... Water or waterside: ....

Structure and Classification of Fungi

In Grades 5–6, the range of the concepts related to fungi is extended to the concept of hypha. Students learn that fungi may have a structure different from that of mushrooms. It is useful to compare the wood mushroom familiar to the students to peronospora and identify the similarities and differences between them. By getting to know the life of peronospora and monilinia, students see examples for the relationship between fungi and other living organisms and the environment. In connection with everyday life, they recognise that fungi may be both harmful and useful organisms.

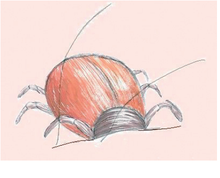
Body Structure, Life Processes and Health of Humans

In Grades 3–4, the structure and biological processes of the TEENAGE BODY and the changes taking place in it are in focus. Students characterise the structure of the teenage body; they can identify and classify the changes typical of adolescence. They can identify the relationship between the structure and the function of the musculoskeletal system, list the stages of digestion and identify their sequential order. They know that the human organism has special structures for the circulation of materials. They know how blood flows; how oxygen and carbon dioxide are replaced in the lungs and tissues. They are familiar with the function of the kidneys and the connection between their excretion function and other metabolic processes. They are aware of the relationship between inheritance and reproduction and understand that human beings – similarly to other living organisms – are in contact with other living and non-living elements of the environment. They know the effects of environmental pollution on the human body and are able to list the criteria of a healthy and pleasant environment.

In health education, the topic of HUMAN HEALTH extends students' knowledge of health acquired in previous years and continues to encourage a habit-forming healthy lifestyle and environmentally conscious behaviour. It helps students develop a realistic self-image and a healthy attitude towards the self. It encourages the emergence of basic moral norms and the acceptance of eternal human values, e.g., health, honesty and knowledge. Increased emphasis is placed on knowledge related to the prevention of diseases, nursing and first aid. Personal and social issues related to the acceptance of sexual development and to the roles of males and females are also a major component of the subject. Separate sessions are dedicated to psychological and behavioural changes and conflicts in adolescence and to the roles of family and social relationships. Students of this age have a great deal of knowledge of health issues relevant to everyday life. They understand the relationship between the regularity, intensity and duration of physical exercise and health; know of the effects and dangers of alcohol and drug consumption and the different degrees of dependence. They know how to recognise and treat different types of bleeding and why and how to remove a tick attached to someone's skin (Task 49).

Task D49

What is the correct method of removing ticks from the skin?



We tear it out with our fingers.
We remove it with special tick tweezers.
We cover it with cream.

Ecosystems

In Grades 5–6, students become familiar with the most important levels of subindividual organisation. They learn that an individual exists in the ecosystem as a special biological system but it does not live its life in isolation but in interaction with other individuals. Students can make a connection between levels of organisation below and above the individual; they realise that the habitats familiar to them operate as systems subject to change in space and time but remaining relatively closed self-regulating structures; and they can give examples for the division of individual ecosystems as a function of environmental factors.

Environmental Protection, Conservation of Nature

Students in Grades 5–6 recognise the difference between the concepts of environmental protection and nature conservation, and know the National Parks of Hungary and the consequences of environmental pollution (Task D50). They are familiar with procedures and technologies (organic farming, bioculture, chemical free agriculture) used to preserve the original condition of nature and the environment. They can give examples for activities of environmental protection and nature conservation.

Task D50

In what order do the following processes take place when the water in a lake is polluted by chemical fertilisers?

The process of decay draws oxygen from the environment.
Dense vegetation blocks the passage of light.
Fish die in large numbers.
Water plants multiply at a fast rate.
Plants die in the absence of light.

The Earth and the Universe

Orientation in Space

In Grades 5–6, the activities related to spatial orientation centre around the spatial interpretation of maps, map reading and map use. By the end of the period, students can read maps at an elementary level and have acquired descriptive map reading skills. Based on their knowledge of cardinal directions and using a key of colours and symbols, students are able to describe what is represented on the map; they can explain what things are and where they are, and can identify the spatial relations between geographical objects. They can use their map reading skills and the given maps' key to colours and symbols in a variety of situations and with a variety of instruments (e.g., on a wall map and in an atlas), with reference to different domains (e.g., continents, regions, landscapes) and on maps of different contents (e.g., on topographic, political or simple thematic maps). In addition to descriptive map reading, students should also be able to reason based on the information on the map: To analyse the facts and data given on the map, to discover and describe the relationships between various geographical and environmental phenomena; and to give some thought to what they see on the map and draw their conclusions.

In the REPRESENTATION OF PHYSICAL SPACE, there is a shift in emphasis towards map-like representation and its coverage extends beyond students' home locality. Students are familiar with and know how to use the methods of discovering space, the tools needed to extract information from a map and the procedures of recording and organising the data obtained. They are able to transfer their knowledge and image of a specific space to other spaces; to extend an area in space, i.e. to imagine the continuation of the landscape (e.g., behind a chain of mountains) in reality or beyond the frame of a picture. The representation of space involves the reducing of scale and the handling of the tools expressing the extent of reduction (scale ratios and linear scales), which enables students to understand and imagine the difference between the sizes in reality and on the map. Cartographic representation involves more than a simple visualisation of spatial or geographical conceptions formed on the basis of experience or information, as these conceptions must be analyzed to complete planning tasks meeting various requirements (Task D51).

Task D51

There is a small town hidden in the hills. A family would like to move here to enjoy the beautiful landscape, the sunshine and the warm weather. All the building sites in the valley have been sold, so the family can only build a house on the hill-side. The picture depicts the conditions at noon on a summer day.

Choose the best site for the family and add their house to the picture. Justify your choice.

The mid-term development plans of the town include the construction of a ski trail. The skiers should be able to enjoy the view of the town and the rising sun as they are skiing. Where should the ski trail be built? Draw it in the picture. Justify your answer.

The assessment of ORIENTATION IN SPACE in Grades 5–6 concerns map reading. The primary goal of diagnostic assessments is to test students' ability to find objects on a map (using an index, grid references and the geographic coordinate system). Students' topographic literacy can be assessed through tasks requiring recognition, labelling and marking (Task D52). Students need to have explicit knowledge of only a few topographic concepts (those needed to find their way on our planet and situate Hungary in Europe; see also the section on the Regions of our planet) but they can be expected to be able to identify them on maps of different types, scales and contents and to use the information extracted from the map to plan a route, construct a model or solve tasks of following or giving directions (see e.g., Task A49).

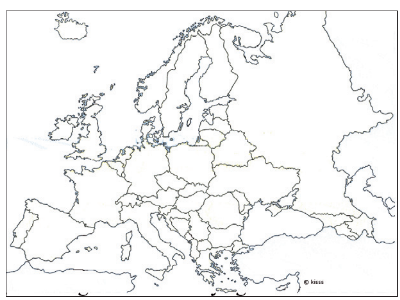
Task D52

This is a line map of Europe.

Mark the borders of Hungary with a colour pencil.

Colour the area of the Mediterranean Sea blue.

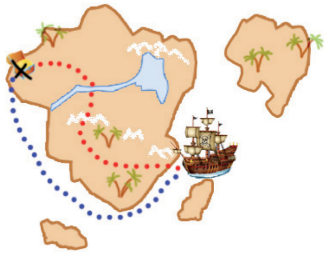
Draw the line of the Carpathian Mountain range on the map.



The diagnostic tasks used for the topic of ELEMENTS OF SPATIAL STRUCTURE AND THEIR HIERARCHY assess students' ability to measure and calculate distances on a map and to extract data needed for estimating journey time. (Task D53).

Task D53

The treasure hunters' boat is approaching the shores of the island where some treasure is hidden in a chest. The crew want to get to the treasure by the shortest possible route.



Which route should they choose?

They should sail along the coast (blue route).

They should walk across the island (red route).

How did the treasure hunters measure the length of the routes on the map?

For the topic of the SPATIAL ARRANGEMENT OF ENVIRONMENTAL PHENOMENA AND PROCESSES, the topographical knowledge of students may be measured with Task D54.

Task D54

Which of the following cities can we imagine to see from an aeroplane flying in a straight line from Budapest to Athens? Use your atlas to answer the question.

Budapest Thessaloniki Belgrade Athens Sofia Skopje

Orientation in Time

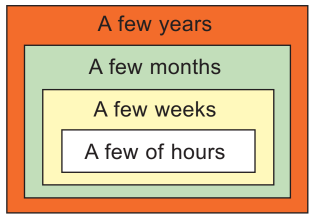
In Grades 5–6, students are able to understand the alternation and periodical recurrence of the parts of the day and the seasons; to measure time; to estimate the duration of events structuring their lives; to create time sequences related to natural phenomena and everyday activities; to compare daily, yearly and historical time scales; and to recognise that living organisms and the students themselves change with the passing of time.

The assessment of students' orientation in DAILY AND YEARLY TIME may now include tasks involving the representation of natural phenomena and various processes of nature on time lines (e.g., marking on a time line the coldest month in Australia or the period when Hungarian rivers typically flood). To be able to orient themselves among the events and processes of the world, students must have a clear notion of the scale of their duration. Task D55 assesses students' ability to perceive the hierarchy of daily, weekly, monthly and yearly periods. With respect to the TEMPORAL ARRANGEMENT OF ENVIRONMENTAL PHENOMENA AND PROCESSES, students in Grades 5–6 need to recognise and order historical time scales.

Task D55

What is the duration of the phenomena listed below?

A) harvesting of crops in Hungary
B) the average number of hours of sunshine a year in the Southern Great Plain
C) lake succession
D) gathering of a storm
E) the passage of flooding along the Hungarian section of the River Tisza
F) a west-east railway journey across Hungary



Surface of the Earth

In connection with the surface of the Earth, at the end of Grade 6 students can identify the major ROCKS OF THE EARTH'S CRUST and some soil types; classify and model simple and complex LANDFORMS; identify the combined effects of external and internal forces in the process of SURFACE SHAPING; label the structures and shapes created by these forces and identify the role of soil formation in the living world, in farming and in social life.

During the period of elementary education, orientation in the environment relies on cardinal directions and basic environmental elements and landforms. Students' level in Grades 5–6 is assessed by Task D56, where the properties of the landscape need to be exploited to achieve a specific purpose.

Task D56

Imagine that you are spending your holiday by the beach shown in the picture.

Along which path would you walk if you wanted to see as many different types of rock as possible?

List the types of rock under your feet as you walk from the sea towards the beach.

The study of geographical facts provides an opportunity for students to learn the methods of observation and demonstration that provide the foundations of future experimentation. The goal is not only to enable students to plan targeted and reasoned interventions in the course of phenomena and processes but also to help them to recognise and understand these processes in operation within their network of interconnections. In Grades 5–6 – as was discussed in detail in the section on the development of thinking skills in connection with science experiments, – students can be expected to know the algorithms of simple experiments, to choose the appropriate tools and methods and to record their experiences in words or in pictures. Task D57 is an example for the assessment of these skills.

Task 57

Steve was given the task to identify limestone among the pieces of rock displayed in the school laboratory.

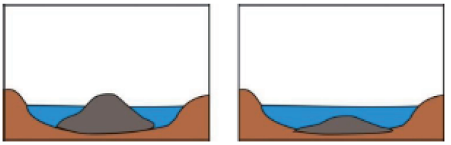
Based on what properties did Steve identify the limestone without any tools?

What experiment could Steve perform to test whether the rock he had chosen was actually limestone?

The design of demonstrations can be assisted by providing graphical information or an outline for the recording of experiences. Task D58 is an example of assessing the design of a demonstration using modelling.

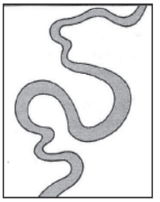
Task D58

Design a sand table demonstration that helps you find out how the landforms shown in the picture have developed.



Tools needed:
Materials needed:
Steps of the demonstration:

Mark one of the locations in the picture where a lot of these forms may have developed in the river. Justify your answer.

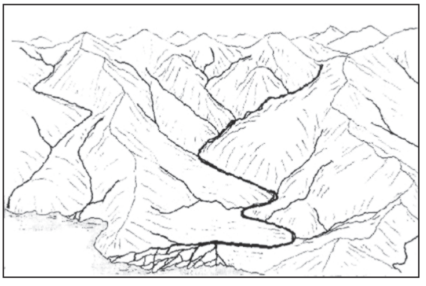


The Hydrosphere and Its Phenomena

By the end of Grade 6, students have learnt that water is in continuous movement with its state cyclically changing and that sunlight has a major role in this process. Students of this age are familiar with the PROPERTIES OF WATER and can perform simple demonstrations with water. They should also know the position of the hydrosphere and the SURFACE SHAPING work of surface waters (erosion and deposition); and should be able to characterise the flow of rivers and their work with sediment in their various sections. In connection with the topic of the surface shaping work of water, Tasks D59 and D60 provide examples for the assessment of students' recognition of concepts in line drawings and on maps in Grades 5–6.

Task D59

What are the characteristics of the river meandering in the mountains shown in the picture?



Draw a blue line over the course of the main river in the area.

Mark with an arrow the direction of its flow.

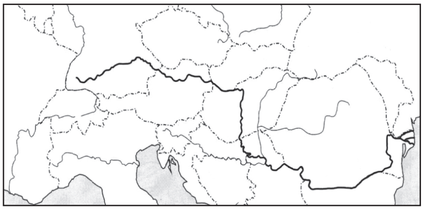
Draw the watershed of the river.
What type of mouth does this river have? Label the picture.

Task D60

This map shows Central Europe. Find this area on the map of Europe in your atlas.

Use the topographic information to decide where the watershed of the Danube may be. Draw it in the picture.

Colour the catchment basin of the Danube on the map.



In Grades 5–6, diagnostic assessments can test students' understanding of the relationship between surface water and groundwater, the classification of types of surface water and types of groundwater, the multidimensional relationship between water and society, the responsibility of the individual and of society in the preservations of the condition of water; and their ability to extract information on hydrological properties from maps and to represent these properties.

The Atmosphere and Its Phenomena

In connection with the atmosphere and atmospheric phenomena, students in Grades 5–6 can be expected to characterise WEATHER PHENOMENA and understand the cause-and-effect relationships between them; to observe and measure the elements of weather, record, chart and interpret the measurement data and draw conclusions from them. Students of this age are able to identify in examples the factors shaping and modifying CLIMATES; to explain the surface shaping effects of atmospheric phenomena in examples and in demonstrations; to recognise the relationship between the atmosphere and society and describe the responsibility of society and the individual in protecting the atmosphere. The topic of weather and climate also provides several opportunities for modelling processes. In Grades 5–6, students need varying amounts of guidance from their teachers in modelling.

Knowledge of the Home Locality and of Hungary

In connection with knowledge of the home locality and of Hungary students can be expected to collect, organise, analyze and present the physical geographical properties, resources and assets of their local area; to use electronic sources to gather factual information on Hungarian people having outstanding, internationally recognised achievements. They should be able to describe the geographical properties of the major regions and types of settlement in Hungary and the Carpathian Basin and compare them according to different criteria and description algorithms; they should know and place on the map the physical geographical, political and historical topographic concepts of the Carpathian Basin; and be able to interpret their sense of Hungarian identity.

In Grades 5–6, students can be expected to apply a landscape characterisation algorithm: The characterisation of a specific landscape according to given criteria, which may apply to the relationship between people and the environment as well as to topographic conditions. It is important to assess students' application of the landscape characterisation algorithm because landscape characterisation is an essential component of the acquisition of geographical knowledge in higher grades (see the study of regional geographical knowledge).

Our Planet in the Universe

In Grades 5–6, students can be expected to describes the CHARACTERISTICS OF OUR PLANET; to classify the materials making up the Earth; to appreciate that the Earth is shaped like a sphere and know the causes and consequences of its spherical structure; to find the continents, oceans and major seas on different maps and globes; and to describe their situation and mark them on outline maps. Diagnostic assessment tasks can require students to describe the STRUCTURE OF THE UNIVERSE and name celestial bodies; to draw a heliocentric model and model rotation and orbital revolution; to observe phenomena in the sky and record, organise and present their experiences.

The topic offers several opportunities for reading data off a chart or diagram and comparing these data (e.g., the area and population of a continent) or representing them (e.g., finding the highest mountain of a continent in the atlas and drawing a diagram showing heights). Task D61 shows an example of finding and interpreting information and data and deriving data from other data. Task D62 assesses students' organisation of celestial bodies in the Universe.

Task D61

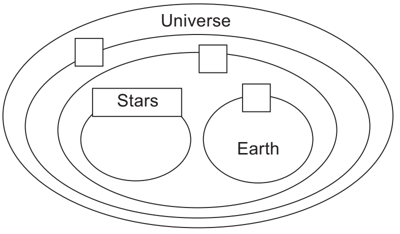
Answer these questions with the help of your atlas.

Which is the largest planet of the Solar System?
In which direction do the planets revolve around the sun?
Does the Earth rotate around its axis in the same direction as it revolves around the sun?
Which planets revolve around the sun faster than the Earth?

Task D62

Name the parts of the Universe. Use the letter labels.

W – the Milky Way
SS – the Solar System
P – planets
M – moons
S – the Sun



Relationship between the Natural Environment and Society

In Grades 5–6, students are able to name the peoples, nations and ethnic groups living in the Carpathian Basin, to collect information and data about them and display or represent the information. They can identify, characterise and categorise economic activities; observe and describe the environmental relevance of economic activities and record the results of their observations. In connection with planning journeys, students of this age can be given tasks where the timetables of long-distance transport routes need to be looked up on the Internet and used in an electronic form to plan the journey.

State of the Environment

Students in this age group are able to observe the elements of landscape transformation and record their experiences; to identify the causes and consequences of environmental degradation; to recognise the depletion of the supply of raw materials, energy and food through examples; to design experiments testing the air, water and soil to reveal the condition of the environment and present their experiences. Students are familiar with the goals, tasks and methods of nature conservation and environmental protection and with the nature of responsible behaviour.

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