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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 20th 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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