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5 Development of competencies across the life span

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Abstract: The selection and measurement of competencies, reflecting educational effects in a lifelong learning perspective, represents a major challenge for the German National Educational Panel Study. Data on the development of competencies serves as a central point of reference for all other parts of the Panel Study. These competencies have to be relevant not only for a successful and responsible individual life but also for a well-functioning modern democratic society. Hence, the aim is not just to describe the development of such competencies, but also to analyze relevant prerequisites, conditions, and courses of competence acquisition. The lifelong learning perspective will shed light on how different competencies are acquired over the life span, how they interact over time and across educational stages, and in which way they may contribute to in-

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dividual and group-specific life-course outcomes. This chapter gives an overview on the selection, rational, and conceptualization of competencies within the National Educational Panel Study.

Keywords: Competencies · Life-span development · Panel study

Kompetenzentwicklung über die Lebensspanne

Zusammenfassung: Die Auswahl, Konzeptualisierung und kohärente Messung von bildungsrelevanten Kompetenzen über die Lebensspanne stellt eine besondere Herausforderung für das Nationale Bildungspanel dar. Daten zur Entwicklung bildungsrelevanter Kompetenzen bilden einen zentralen Referenzpunkt für alle anderen Bereiche des Bildungspanels. Die ausgewählten Kompetenzbereiche sollten daher sowohl für ein erfolgreiches, verantwortungsvolles individuelles Leben bedeutsam sein, als auch für eine moderne demokratische Gesellschaft insgesamt. Ziel ist es, domänenspezifische Kompetenzentwicklungen über die Lebensspanne nachzuzeichnen und zudem wichtige Voraussetzungen, Bedingungen und Erwerbsverläufe zu analysieren. Die Lebensspannenperspektive der Kompetenzmessungen im Nationalen Bildungspanel wird Aufschluss darüber geben, wie verschiedene Kompetenzen im Lebenslauf erworben werden, wie sie in ihrer Genese und Entwicklungsdynamik innerhalb und über Bildungsetappen hinweg miteinander interagieren, und in welcher Weise sie zu individuellen und gruppenbezogenen Lebensläufen (inkl. Lebenszufriedenheit, Bildungsrenditen) beitragen. Das Kapitel gibt einen Überblick über die Auswahl, Begründung und Konzeptualisierung der Kompetenzmessungen im Nationalen Bildungspanel.

Schlüsselwörter: Kompetenzen · Lebenslange Entwicklung · Längsschnittstudie

5.1 General remarks on the concept of competence and on the dynamic of competence development

Educationally relevant competencies are often referred to as functional, context-bound, domain- and demand-specific (cognitive) achievement dispositions that are subject to educational influence and interventions (e.g., reading literacy, mathematical literacy) (cf. Rychen and Salganik 2001, 2003; Weinert 2001). These domain- and demand-specific competencies are distinguished from (a) (primary) domain-general and rather context-free cognitive capacities (e.g., fluid intelligence or working memory capacity) as well as from (b) specialized content-specific knowledge structures and procedural skills. Furthermore, educationally relevant competencies are often conceptualized as either curricular (i.e., subject-bound) or cross-curricular (i.e., cross-subject).

From an empirical point of view, there has been much research on the development of various competencies in school (e.g., reading and mathematics; cf. NCES 1995; Prenzel et al. 2006; Weinert and Helmke 1997), and social disparities are documented extensively (e.g., Sammons 1995). Nonetheless, there is comparatively little research on these competencies in adulthood, and, in addition, little is known about the cumulative development of competencies across educational stages. Thus, important empirical questions in the National Educational Panel Study (NEPS) relate to the development and relevance of these competencies beyond school, their importance for future job careers, and their impact on general life satisfaction. How do they develop further in different educational contexts? In which way do they contribute to the acquisition of competencies specific to tertiary education or working life (e.g., the mathematical competencies acquired in school may differ from those necessary for and acquired through tertiary education at university level and from those necessary for posttertiary work in this area)? How does the cross-stage acquisition of competencies vary across subgroups depending on socioeconomic status and migration and/or language background?

Thus, central topics of the NEPS refer to the questions: "In which way do domain-specific functional competencies emerge on the basis of individual prerequisites for learning and formal as well as nonformal/informal education during different educational stages (preschool level, elementary and secondary school level, university level, vocational training, and on-the-job training)?" and "What is the significance of specific competencies throughout the life span?". These questions address:

1. The interrelation between competence development and the themes of the other four "pillars" of the NEPS, i.e., family education, education in and outside of institutions (focus of pillar 2; see Chap. 6, this volume), educational decisions and their distal and proximal determinants (focus of pillar 3; see Chap. 7, this volume), issues of migration (focus of pillar 4; see Chap. 8, this volume), and educational returns (focus of pillar 5; see Chap. 9, this volume).
2. The analysis of developmental relationships between the acquisition of (a) basic domain- and demand-specific functional competencies (e.g., reading literacy, mathematical literacy), (b) domain-general individual abilities/capacities, and (c) the construction of content-related knowledge and procedural skills as indicated by stage-specific outcome measures.

From a life-span perspective, it should be noted that the development of basic competencies is subject to a stage-specific dynamic that may change across educational stages: Competencies (e.g., reading, mathematical, and scientific literacy), which are subject to domain-specific development during the school age period in which they form a subject-specific focus, become kinds of cross-curricular basic competencies during later stages (job training and tertiary education). In the same vein, when entering elementary school, most children have already acquired a host of language-based as well as cognitive competencies (Damon and Lerner 2006). Although these competencies were acquired in a highly domain-specific way during their first years of life (Weinert 2000), in school they can be conceptualized as cross-subject basic competencies for school learning.

In addition, developmental psychology as well as research into the acquisition of expertise support the view that the interrelations between domain-general psychological capacities (e.g., fluid intelligence, working memory) and the acquisition of domain-specific competencies may vary systematically by age, educational stage, and expert status—much the same as interrelationships between different competencies may change over time (Ericsson et al. 2006; Weinert 2000, 2007a). The NEPS will contribute considerably to our knowledge about the developmental interrelations between (a) domain- and demand-specific competence acquisition within and across educational stages, (b) previously acquired as well as not yet developed, more general cross-domain abilities and psychological capacities, and (c) the evolving content-specific knowledge base including procedural skills.

5.2 Which competencies are included in the NEPS: An overview

From a lifelong learning perspective, looking at "outcomes" of educational processes cannot be the only objective of the NEPS. The "outcomes" at a certain age function as conditions for development in the ensuing stage. One of the major challenges is to describe and explain the processes of competence development within and across educational stages while also analyzing their relevance for future prospects. This implies both a sufficient coverage of important competencies and a (pragmatically and theoretically thoughtful and justifiable) concentration on certain relevant competence domains to be assessed over the life span. With regard to the five pillars of the NEPS, it seems necessary to select competence domains that promise insights into the stability and plasticity of competence development, the (long-term) effects and consequences of institutional efforts to influence these developments, their relevance for educational decision making, and educational returns across the life span, while also additionally focusing on competence acquisition in certain social groups such as migrants.

Recent discussions about the relevance of competencies across the life span place special emphasis on cognitive competencies as well as on various social skills, motivational dispositions, attitudes, and expectations (see e.g., the Definition and Selection of Competencies (DeSeCo)—Project and the Programme for International Assessment of Adult Competencies (PIAAC); see also, Artelt et al. 2003). Obviously, cognitive and noncognitive components interact in everyday applications. Nevertheless, it seems reasonable to distinguish systematically between cognitive and noncognitive components from both an analytical point of view as well as from the perspective of a longitudinal reconstruction of the development of educationally relevant competencies. A distinct assessment of constructs allows for the analysis of the interplay as well as the developmental dynamics of these components (Weinert 2001).

For the NEPS, we concentrate on both cognitive and noncognitive (social and motivational) competencies. While some competencies will be reconstructed in their lifelong internal dynamics of developmental change, the assessment of others will depend on and vary according to the affordances of certain educational stages (see below). Thus, with respect to measurement, we differentiate competencies that are measured in a coherent way across the entire life span, aiming at a comprehensive reconstruction of their internal dynamics of emergence and developmental change over the life course, from competencies that are assessed with more stage-specific instruments.

Central research questions regarding the development of basic domain-specific functional competencies are the following: (a) How and to what extent do domain-general and content-free cognitive capacities shape the effects of schooling and the development of these basic functional competencies? (b) What are the relationships between (selected) school-curriculum-specific skills and the development of these basic functional competencies? These two research questions are not only interesting from a theoretical/analytical point of view, but are also directly relevant to the field of applied education. Implications for the assessment agenda are as follows: The assessment of basic (subject-)domain- and demand-specific competencies that are sensitive to learning and institutional efforts (i.e., that are the result of individual prerequisites and learning processes, along with family based and institutional as well as nonformal/informal learning opportunities) needs to be complemented by analytically oriented measures of domain-general and more culture-fair capacities of the individual (i.e., indicators of abstract and logical reasoning, and indicators of processing speed) that enable the acquisition of domain-specific competencies through interactions with environmental stimuli and learning opportunities. In addition, these rather content-free areas will be complemented by more specific content-related variables and stage-specific outcome measures. The major focus thus lies on analyses of the developmental trajectories and interactions of the corresponding competencies, capacities, and skills along with assessments of their relevance for future educational and occupational careers as well as for life satisfaction.

This conceptualization can also be applied to developmental phases beyond school. Again, basic functional competencies that have now become cross-curricular (e.g., mathematical, reading, foreign-language, and scientific literacy) are complemented with subject-specific knowledge, attainment, and skills in tertiary education as well as job-related proficiency outside university. This approach permits an analysis of the relevance of basic domain-specific functional competencies as well as their further development (stagnation or decline) beyond formal schooling and the interplay of these competencies with job-specific attainment, competencies, or skills or with competencies specific to selected fields of tertiary education. Of course, from a pragmatic point of view, it is obviously necessary to concentrate on a carefully selected number of types of jobs and fields of tertiary education.

In addition, from the perspective of lifelong learning as well as from the perspective of the five pillars of the NEPS, we suggest broadening the perspective systematically by including additional competence areas, specifically metacompetencies (see below).

To summarize, four areas of individual abilities and competencies are differentiated and assessed in the NEPS: (A) domain-general cognitive abilities/capacities, (B) domain-specific cognitive competencies, (C) metacompetencies and social competencies, and (D) stage-specific (curriculum- or job related) attainments, skills, and outcome measures. These areas will be described in more detail below.

5.2.1 Area A: Domain-general cognitive abilities and capacities

From a developmental perspective, it is necessary to point out that it is not just acquired domain-specific competencies that are subject to typical age- or development-related changes over the life span. The same also applies to domain-general abilities that are characterized as being relatively context-free and culture-fair. These basic individual abilities and capacities have been described and extensively explored within the framework of intelligence theories, and they form an important basis of intelligent thinking and action (cf. Baltes et al. 2006). As rather general individual abilities/capacities, they have been conceptualized as “fluid intelligence” (Cattell 1971) or “cognitive mechanics” (Baltes et al. 2006). Whereas the mechanics (fluid intelligence, basic capacities) refer to performance differences in the speed of elementary cognitive processes, in the capacity of working memory, or in the ability to apply deductive or analogous thinking in new situations, the intellectual pragmatics (Baltes et al. 2006; or crystallized intelligence, Cattell 1971) refer particularly to the declarative and procedural knowledge and skills that a person acquires during the life course. Education-relevant competencies in the way emphasized by the NEPS (see area B) tend to belong more to intellectual pragmatics. From a developmental and educational point of view, both components of cognitive architecture, that is, both intellectual pragmatics and intellectual mechanics are subject to typical age-related changes across the life span. Nonetheless, they (a) reveal different characteristics of change over their course and (b) are influenced to a varying degree by different determinants (cf. Baltes et al. 2006).

Considering cognitive performance, it is important to note that the contrast between cognitive mechanics and cognitive pragmatics does not imply that they are independent of each other. This is one reason why the domain-specific measurements of competencies in the NEPS require a supplementary assessment of at least some brief indicators of intellectual mechanics. Thus, although the NEPS focuses specifically on the acquisition of education-dependent, domain-specific competencies, these assessments are to be supplemented by additional indicators of cognitive mechanics that can be taken to be more "culture-fair" and language-free. From not only a theoretical but also an empirical and pragmatic perspective, we have proposed that cognitive mechanics should be assessed through two indicators within the NEPS, in particular, through:

- A1: Tasks assessing figural reasoning. To avoid partial overlaps with the specific competence domains assessed in the NEPS, no verbal or numerical reasoning tasks were proposed that are more likely to tap language and mathematical skills.
- A2: Tasks assessing perceptual speed. These are preferred to other speed measures, because they tend to be more language-independent and more culture-fair than, for example, rapid naming tasks.

5.2.2 Area B: Domain-specific cognitive competencies

With respect to the cognitive domains, discussions about the relevance of competencies for future prospects are influenced strongly by international large-scale assessments of students' and adults' performance (e.g., the *Programme for International Student Assessment* (PISA), the *Third International Mathematics and Science Study* (TIMSS), the *Adult Literacy and Life Skills* (ALL) Study, the *Programme for the International Assessment of Adult Competencies* (PIAAC); see also Chap. 3, this volume). The frameworks of these assessments place a special emphasis on basic school-related and demand-specific cognitive competencies. There is overall consensus on the relevance of the following competencies: (German-)language competencies (including reading literacy), mathematical literacy, scientific literacy, and foreign-language competencies (see, e.g., Bynner 2004; Forum Bildung 2002; International ICT Literacy Panel 2002; Konsortium Bildungsberichterstattung 2006; OECD 1999, 2006; Rychen and Salganik 2001, 2003; Tenorth 2004).

Especially the OECD's Programme for International Student Assessment (PISA) raised the claim that competencies such as reading, mathematical, and scientific literacy are not only school-related competencies in a narrow sense but also highly relevant for success in later life. Literacy is understood as a predictor for successful participation in society (OECD 2006). Within the conceptualization of domain-specific competencies, the notion of participation is considered as functional literacy. This leads to an assessment that relies heavily on everyday problems which are more or less distant to school curricula. There are many reasons why competencies in the sense of functional literacy should be included in the NEPS—one being the assumed relevance largely agreed upon in educational policies, educational sciences, as well as the general public. Another reason is the importance of linking the NEPS to international large-scale assessments. Additionally, the NEPS offers unique opportunities for longitudinal analyses of the assumed relevance of these basic functional competencies for future prospects, the courses of developmental change in these basic competencies, and their interrelations with other competence domains and variables assessed in the NEPS.

Thus, in the NEPS, we are measuring the following competence domains:

- B1: German-language competencies (reading literacy and oral language comprehension)
- B2: Mathematical competencies (mathematical literacy)
- B3: Natural science competencies (scientific literacy)

In addition, we shall assess indicators of foreign-language competencies.

In particular, the competence domains B1–B3 will be assessed consistently and coherently across the life span so that their genesis and cumulative development can be reconstructed across educational stages. The acquisition of foreign-language competencies in the sense of learning one (or several) language(s) beyond the acquisition of the specific first language(s) will not be assessed until later school age. Here we focus on English language competencies (see Chap. 15, this volume). In addition, indicators of first-language competencies will be assessed when these do not refer to German. Here we focus on Russian and Turkish language competencies. This is the responsibility of the expert team in pillar 4 (Migration, see Chap. 8, this volume).

Challenges of modeling domain-specific cognitive competencies. Modeling domain-specific competence development over the life span is confronted with at least two major challenges: (a) the stipulation of benchmarks for the judgment of competence development over the life span (which also means for different requirements and standards across the life span) and (b) a coherent modeling of competence development over different educational stages allowing the description of cumulative developmental progress over time (scale anchoring). These challenges will be illustrated in the following paragraph.

(a) Although the labels (reading, mathematics, science) remain the same, the corresponding competence domains change during the life span. The school-subject domain obviously offers a different point of reference to that of the scientific discipline. A fixation on a school-related competence model implies that further competence development after formal schooling would not be covered appropriately in the NEPS, even though analyzing the extent to which school-related competencies (e.g., mathematical) are instrumental for further studies, different jobs, or everyday problem solving would be an interesting task. From this perspective, it seems necessary to consider multiple reference points. These can be organized around life coherences (with corresponding domain-specific demands). One approach would be to use institutional learning environments (school, vocational training, tertiary education, on-the-job training) or everyday life experiences (e.g., political and cultural participation, health behavior). Different reference points can be accounted for by applying structural models of domain-specific competencies that disengage from school-subject-related and academic structuring and aim to identify (declarative/conceptual and procedural/process-related) core components of competence. A concrete example can be found in the PISA approach (OECD 2003) of modeling mathematical competencies around "overarching ideas" (space and shape, change and relationships, quantity, uncertainty). These overarching ideas can be applied not only to mathematics as an academic discipline but also to everyday life as a tool. When describing and analyzing competence development across the life span around these ideas, it seems likely that the use and relevance of mathematical competencies in different life circumstances can be assessed adequately, and that possible future trends can be described. In a similar vein, modeling of "processes/procedures" for other domains seems possible as well. In the domain of science, these are "big ideas" or basic components of scientific thinking and working (e.g., identifying scientific issues, explaining phenomena scientifically, using scientific evidence). With respect to reading literacy, the requirement of retrieving information, interpreting texts, and of reflection and evaluation can be subsumed under central reading processes and demands.

(b) The above-mentioned example for modeling mathematical competencies around overarching ideas can be seen as an example for coherent competence models that are necessary for the description and analysis of cumulative development. Using the concept of overarching ideas allows us to study whether and to what degree traditional computing demands in everyday life (shopping, calculating the costs of a cell phone, or making leasing contracts) are instrumental for the stabilization of competencies in the field of quantity; and to ask whether further developmental progress in the field of space and shape or the field of change and relationships is linked rather closely to the domain of advanced studies or to the specifics of a job. In the field of scientific competence, the thematic context of "health" can be used as a coherent reference point for a lifelong perspective, making it possible to study changes and development in scientific competence in relation to aspects of health. Again, these examples show that content-related and theoretically based developmental trajectories should be formulated for domain-specific competencies. If it is possible to master these challenges in the process of modeling competence development, the NEPS will contribute significantly to our understanding of fundamental developmental processes in educational contexts across the life span. These considerations result in the steps specified in the next paragraph that apply to each of the domain-specific cognitive competencies (area B1–B3) to be assessed in the NEPS.

Framework for each competence domain and scaling issues. For each domain, a competence model has been developed (or is about to be developed) that describes a consistent structure of that competence domain across ages and cohorts. These theoretical assumptions as well as their operational characterizations are to be specified in the competence framework. A short overview of these frameworks for each competence domain under study is presented below. Based on these models, test instruments are being developed for the various age groups. Item pools are pre-tested in qualitative and quantitative pilot studies and then analyzed and selected by using item response theory. Combined with additional linking studies or specific anchor item designs the newly developed instruments should allow for a coherent assessment of competence development over the life span.

5.2.2.1 Area B1: Assessment of german-language competencies (reading literacy and oral language comprehension) across the life span

Being competent in the lingua franca used by the majority of society is indisputably one of the central, education-relevant cognitive competencies. It is exceptionally significant for taking advantage of education opportunities and participating in a society's political and cultural life. In fact, language is not only an important means of communication in everyday life and work but also the object, learning environment, and medium of a variety of formal and nonformal/informal learning contexts. At the same time, language forms an important coding and (self-) control system with a lasting influence on not only cognitive but also social and sociocognitive development (see, for a summary, e.g., Weinert 2006).

Language acquisition is viewed, on the one hand, as a primary, genetically anchored basic human ability (Geary 1995). Nonetheless, both international studies and research in German-speaking countries now show, on the other hand, that even early language acquisition is influenced in a lasting way by social and education-related family background variables (e.g., Weinert et al. 2010). The social disparities that have become apparent in later school age through international comparisons of academic achievement, particularly in Germany (e.g., Baumert et al. 2001) are attributed in part to differences in verbal competencies (Esser 2006; Stanat 2006). Language is *the* central medium for the acquisition of content- and problem-solving-related knowledge including important self-regulated learning abilities. In schools as well as in tertiary education, verbal activities such as "formulating and solving tasks", "listening to teachers' lectures and answering teachers' questions" (which are used as an illocutionary tactic relative to everyday questions), "explanation or reformulation", as well as "justifying, explaining, arguing, and estimating", and, not least, "processing written texts" are a central means of knowledge acquisition and knowledge transfer to the next generation. Language and verbal communication also play an important role in social interaction and both social and sociocognitive development, as already demonstrated by the Soviet cultural historical school of Vygotsky (cf. Wertsch 1996; see also, Weinert 2007b).

Despite different conceptualizations of the construct "verbal competence," there is broad consensus that language and verbal competencies can be viewed from both a structural and a communicative-functional perspective. This analytic distinction does not imply, as sometimes assumed mistakenly, a corresponding separation when concrete communication and acquisition situations are to be considered. The function and structure of language are inseparable here; both aspects are mutually dependent and combine to form language. Thus, on the one hand, component models of language (differentiating between grammar, lexicon, pragmatics, etc.) have proved their worth from both a developmental as well as from a clinical and educational perspective, and they have been well received in language diagnosis. On the other hand, from an education-related perspective, the integrative functional verbal abilities have been emphasized, with distinctions generally being made between productive and receptive as well as between auditory and written verbal competencies in the sense of reading competence, listening comprehension, writing, and communicative or interactive speech (cf., also, Jude and Klieme 2007). When deciding how verbal competencies should be conceptualized and measured within the NEPS, it was necessary to consider not only theoretical aspects but also the practical demands within the framework of a large-scale study like NEPS. The aspects assessed have to retain their meaningfulness across a broad range of ages and age cohorts in terms of both their relevance for and their dependence on education processes. Against this background, the NEPS concentrates on assessing: *reading competence* and *listening/oral language comprehension.*

The framework depicted in Table 1 is used to design test instruments to assess reading literacy across the life span. In addition, an indicator of reading speed will be applied.

With respect to the listening/oral language comprehension framework, we differentiate between word, sentence, and discourse level. Specifically, we assess receptive vocabulary, which has proved to be one of the best indicators of both crystallized intelligence and language competencies (see, for a short summary, Weinert et al. 2007). In young children, we add measures of sentence comprehension to assess receptive grammar; later on, we shall assess functional listening comprehension on a text or discourse level. The

Table 1: Conceptual differentiations of the reading competence framework

Comprehension requirement[a]	*I. Information retrieval:* • Identifying a statement in a text when the wording is identical in both the task and the text • Identifying a statement in a text when the wording in the task and the text deviate from each other *II. Information integration and interpretation:* • Integrating statements from successive sentences • Integrating statements from several sentences or sentences located far apart • Comprehension of important ideas in the text, which requires the ability to comprehend relevant text passages that are larger or more complex *III. Reflection and evaluation:* • Understanding the main statement of a text, the main content, the main event • Recognizing the purpose and intention of a text and being able to judge its credibility • Drawing further inferences on the basis of a text, which requires the integration of background knowledge
Functions of texts/or text types	• Communication of factual information, e.g., factual texts, reports, articles • Commentary function, e.g., comments, glossaries, essays • Literary-aesthetic function; exclusively prose texts, e.g., short stories, passages from novels • Instructional/Product information, e.g., assembly instructions and user instructions, package inserts for taking medicines • Appeals/Announcements/Advertising, e.g., job vacancies, vacation travel ads
Age level	• Adaptation with respect to text difficulty as well as the selection of topics

[a]Note that these eight (I.–III.) types of demands for the reading items are neither meant as distinct dimensions nor as a statement on the hierarchy of information processing

conceptualization of functional listening/oral language comprehension will be comparable to reading literacy in some aspects (e.g., comprehension requirements) but different in others (e.g., discourses with more than one speaker). Memory and especially reading requirements will be reduced as far as possible and the texts/discourses will be quasi-authentic and presented by sound carrier. The detailed framework is still in the making.

5.2.2.2 Area B2: Assessment of mathematical literacy across the life span

Mathematical literacy is considered to be an important key competence in today's knowledge society, and increasing importance is being assigned to the requirement to understand and apply mathematical data and methods in manifold situations (NCTM 2003). For instance, mathematical literacy is necessary in many professional fields in which calculations must be drawn up, mathematical or abstract problems must be solved, logical argumentation is called for, or different representations of numbers and relations in newspapers must be understood. In the private sphere, mathematical literacy is also called for if one, for example, wants to compare and evaluate different finance or insurance models.

The importance of mathematics in our present society can also be seen from the fact that the OECD regularly conducts international comparisons of education systems by surveying the mathematical literacy of young people in, for example PISA. Mathematical literacy is thereby understood as "an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgments and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen" (OECD 2003, p. 24). It thereby describes the extent to which students and also adults can flexibly apply the mathematics they have learned in school to problematic situations mostly outside the field of mathematics.

Although the importance of mathematical literacy for successful participation in society is uncontested, up until now, little empirically founded knowledge has been gained on how it develops over the life span from preschool to late adulthood. How do numerical competencies at the preschool age influence mathematical literacy in elementary school? How do mathematical skills develop over the course of schooling? Which role does mathematical literacy play when progressing to the next level in education? How does mathematical literacy differ in adulthood?

In order to survey mathematical literacy over the life course, we developed a theoretical framework that defines the structure of mathematical competence for all age groups. The starting point for this has been the comprehensive competence structure for four age groups described in the National Council of Teachers of Mathematics framework conception (NCTM 2003) and the framework for mathematical literacy of 15-year-old students in the OECD's PISA (2003; see OECD 2003). The framework for the assessment of mathematical competence in NEPS differentiates between mathematical content areas and between mathematical and cognitive processes required for solving the test items (Table 2). This framework is used for the development of test instruments for all age groups (see Ehmke et al. 2009).

Table 2: Conceptual differentiations of the mathematical competence framework

Content areas	*I. Quantity:* • Understanding numeric phenomena as well as quantitative relationships and patterns • Using numbers to represent quantities and quantifiable attributes of real-world objects (counts and measures) • Understanding the meaning of operations, mental arithmetic, and estimating *II. Change and relationship:* • Understanding mathematical manifestations of change, functional relationships, and dependency among variables • Expressing mathematical relationships given in equations or inequalities • Understanding mathematical relationships given in a variety of different representations *III. Space and shape:* • Understanding spatial and geometric phenomena and relationships • Analyzing the components of shapes and recognizing shapes in different representations • Understanding the properties of objects and their relative positions *IV. Data and chance:* • Understanding probabilistic and statistical phenomena and relationships • Organizing data and using graphical representation forms • Analyzing collected data and drawing conclusions from it
Mathematical and cognitive processes	These include: • Understanding and providing mathematical argumentations • Communicating mathematical ideas • Mathematical modeling • Solving mathematical problems • Understanding and handling different representation forms • Applying technical skills
Age level	• Adaptation with respect to task difficulty as well as the selection of mathematical concepts

5.2.2.3 Area B3: Assessment of scientific literacy across the life span

Scientific literacy enables an individual to participate in a society in which science and technology play a significant role. A large proportion of the problems and issues that individuals encounter in their daily lives require some understanding of science and technology before they can be fully understood and addressed. Current debates about the desired outcomes of science education thus emphasize the importance of a science education for all people (Osborne and Dillon 2008). Such an education would provide a basis for lifelong learning that would also have an impact on career perspectives. This is particularly true when scientific literacy is conceptualized as consisting of the knowledge, the competencies, and the attitudes that are needed for solving everyday problems. These problems require a flexible application of acquired knowledge that is appropriate to the particular situation. A corresponding conception has been used in the PISA study. It was elaborated in detail for the framework conception of PISA 2006 with its focus on science (cf. OECD 2006; Prenzel et al. 2007). Rather than focusing on the reproduction of memorized knowledge, PISA aims to assess the ability to apply one's existing scientific knowledge in different everyday contexts and situations. This broad idea of literacy recognizes the importance and relevance of the competencies, knowledge, methods, and values that define the scientific disciplines and that are considered to be of great importance for an

Table 3: Conceptual differentiations of the scientific literacy framework

Concepts	Content related components (knowledge of science, KOS) *Substances:* • Relation between substances and particles • Relation between structure and properties of matter • Chemical changes of matter *Systems:* • Different systems but also elements of one specific system are interacting with each other • Systems are characterized by specific properties (e.g., regulation and control, conversion of matter or energy) • Stable conditions are systems in equilibrium *Development:* • Living systems change with time and are characterized by development • Individual development is caused by genetic heritance and environmental influences • Humans directly and indirectly change the environment *Interactions:* • The interaction of different bodies can lead to deformation or changes in the state of motion • Energy can interact with matter. During this process, both energy and matter can change their properties
	Process related components (knowledge about science, KAS) *Scientific inquiry and scientific reasoning:* • Identifying scientific issues in different contexts • Deducing information context-related • Observing and explaining phenomena • Postulating, testing and evaluating hypotheses and theories • Evaluating and using scientific evidence • Measurement and measurement errors
Contexts	The concepts form the basis for scientific literacy which is required in the following selected *contexts*: *Health:* • Nutrition, maintenance of health, diseases and control of diseases, infection and epidemics *Environment:* • Pollution, waste disposal, sustainability, quality of life, nature *Technology:* • Materials, devices, processes, transportation, sources of energy, genetic modifications

actively participating citizen. Our rapidly changing and developing society increasingly demands scientific literacy in order to understand and make use of technological innovations, to adequately face environmental challenges (like, e.g., climate changes), and to reflect on one's own actions as a responsible citizen (cf., e.g., AAAS 1993; Bybee 1997). Alongside a more content-oriented basic understanding of scientific concepts and facts (knowledge of science), PISA also emphasizes the importance of a more process-oriented basic understanding of scientific thinking and reasoning as well as of scientific methods (knowledge about science). The latter enables people to use an evidence-based approach when they face new or contradictory information in their everyday lives. Scientific methodology is an expression of an analytical, rational, and reflective approach toward an understanding of our world. As a result, scientific literacy is becoming more and more important in a world that, in turn, is continually becoming more and more complex.

The NEPS aims to assess the development of scientific literacy over the life span. Thus, a theoretical framework was developed that defines the structure and content of scientific literacy for all age groups. The PISA 2006 framework of scientific literacy was chosen as a starting point, because it explicitly outlines what 15-year-old students should know, value, and be able to do in situations involving science and technology (OECD 2006). Like PISA, the NEPS framework conceptualizes scientific literacy in everyday situations; namely, within the three contexts health, environment, and technology. These contexts were chosen because of their importance and relevance with respect to everyday life and lifelong learning processes. Similar to PISA, the NEPS framework also differentiates between *knowledge of science (KOS)* and *knowledge about science (KAS)*. *Knowledge of science* is assessed within the four concept areas substances, systems, development, and interactions. *Knowledge about science* is concerned with the two concepts scientific inquiry and scientific reasoning. These concepts are widely regarded as representing central and important aspects of scientific literacy (AAAS 1993). The NEPS framework of scientific literacy is presented in Table 3.

5.2.3 Area C: Metacompetencies and social competencies

Over and above the assessment of cognitive competencies, we have suggested broadening the perspective systematically and including additional competence areas—specifically metacompetencies and noncognitive competence domains.

When selecting competence domains for a national panel study, a major challenge is to appropriately cover concepts and areas relevant to certain age groups (like the middle aged and aged) that have been widely neglected by earlier model building and research designs in education. Do competencies acquired early on in institutional settings remain as relevant in adulthood as they were before? Which indicators adequately cover life satisfaction or the tendency to act in a reflected and responsible way? Which of the competencies that can be covered in a large-scale panel study and mapped with the pillars of the NEPS play a significant role for the aged? Learning processes subsequent to compulsory education need to be regulated by individuals rather than educational institutions. Learning becomes more and more dependent on the initiative of individual people (or families, unions, employers). The farther away from formal education, the higher the necessity to initiate and regulate one's own learning as well as to form decisions about the contents of learning. To cover these metacompetencies, which are regarded as central for middle-aged groups, we decided to broaden the set of indicators and include indicators of metacognition and self-regulation.

Especially for the middle-aged and aged groups, aspects of social behavior and cooperation as reflected in interpersonal skills may be of high impact (i.e., cooperation with others, working together in a team, perspective taking). Compared to the competencies mentioned in area B above, which will be described in terms of their developmental trajectories in the NEPS, the measurement and status of social behavior and personality indicators is slightly different. A reconstruction of the internal developmental dynamic of their emergence and development across the life span is hardly the main focus of the NEPS; instead, they will be analyzed primarily with respect to their role (i.e., as predictors, moderators, possibly compensators) for competence development within educational stages and as predictors between stages. This means that these indicators are chosen with specific reference to the educational stage under study and thus may vary slightly from those chosen in yet another stage, both in terms of content as well as in terms of their relative weight/importance for a specific stage.

NEPS includes direct and/or indirect measures of:

- C1: Metacognition and self-regulation
- C2: Information and communication technologies (ICT) literacy
- C3: Social competencies

Finally (see Chap. 10), we shall include a brief indicator of rather stable dimensions of personality (for a very economic instrument for measuring the Big Five, Asendorpf 2007) as well as indicators of achievement motivation, personal goals, general and topic-related interests as well as of general and domain-specific self-concept. These latter aspects are assessed by questionnaires and thus will not be detailed in this article (see Chap. 10, this volume).

Metacognition. Metacognition concerns knowledge about and control over one's own cognitive system. Drawing on the work of Flavell (1979) and Brown (1987), the NEPS distinguishes between declarative and procedural aspects of metacognition. Declarative metacognition refers to the knowledge about memory, comprehension, and learning processes that an individual can verbalize. This includes knowledge about the strengths and weakness of one's own memory and one's own learning, as well as knowledge about ways and means (e.g., general and domain-specific strategies) of attaining cognitive learning and achievement goals. In the NEPS, declarative metacognition is being assessed with a scenario-based metacognitive knowledge test (see Chap. 10, this volume). Procedural metacognition, in contrast, focuses on how the learning process is regulated through planning, monitoring, and control activities. In the NEPS, it is being measured along with the domain-specific competence tests in which participants have to estimate their own achievement score in the respective test.

ICT literacy. In our modern knowledge and information society, the ability to search for information and to handle information and communication technologies (ICT) competently is indispensable for coping with a host of demands in various life domains (e.g., ETS 2002; NRC 1999; Wirth and Klieme 2002). The ability to comprehend, use, and communicate information conveyed by the electronic media is not just important for cop-

Table 4: Conceptual differentiations of the ICT literacy framework

Competencies	• Information literacy: ability to recognize when information is needed and have the ability to locate, evaluate, and use the needed information effectively • Technological literacy: underlying knowledge of hardware, software applications, networks, and elements of digital technology
Process components	• Define: using ICT tools to identify an information need • Access: basic knowledge and basic operations (e.g., opening, saving, and printing files) • Manage: using ICT tools to locate information • Create: using ICT tools to adapt, apply, design or invent information • Integrate: using ICT tools to summarize, compare, and contrast information from multiple sources • Evaluate: judging the degree to which information satisfies the needs of the task in ICT environments, including determining authority, bias, and timeliness of materials • Communicate: communicating information properly in its context (audience, media) in ICT environments
Computer and Internet applications	• Operating system/hardware • Word processing • Spreadsheet/database • E-mail/communication tools • Search engines/Internet

ing with professional tasks in many workfields. The growing encroachment of ICT into all walks of life (ETS 2002) is also granting these abilities a major status in the everyday world. Therefore, mastery of ICT can be viewed as a general cultural technique whose acquisition is an essential precondition for successful participation in society and for the fulfillment of personal and career goals (e.g., Katz and Macklin 2007; Konsortium Bildungsberichterstattung 2006). Current conceptions of ICT literacy emphasize the importance of a goal-directed and problem-oriented approach to contents and information conveyed by electronic media (NRC 1999). Therefore, ICT literacy refers particularly to information-related competencies (e.g., location and access of information) for which technology-related competencies (declarative and procedural knowledge about computer and Internet applications) are also a prerequisite (e.g., Eisenberg 2008; Katz 2007) (see Table 4).

Social competencies and self-regulation. For these areas, special expert reports have been commissioned to compare the measurement instruments available for different stages and evaluate their coherence (Arnold et al. 2009; Stamov-Roßnagel et al. 2009). These areas are being assessed predominantly by questionnaires and more stage-specific instruments and are therefore not treated in any more depth within this chapter (see Chap. 10, this volume).

5.2.4 Area D: Stage-specific (curriculum- or job-related) attainments, skills, and outcome measures

In addition, a selection of stage-specific abilities, attainments, and skills will also be assessed. For schools, for example, this means that the assessment of the competencies described under area B will be supplemented by collecting data on selected close-to-curriculum abilities and skills; and for tertiary education and vocational training, that some study-subject- and job-related attainments and skills will also be assessed for selected subjects and professions. This will permit an estimation of the stage-specific significance of the competence domains described under area B while simultaneously providing—in combination with grades and certificates—a stage-specific educational outcome measure. The major responsibility for conceptualizing these measurements belongs to the expert groups focusing on specific educational stages (see Chap. 12–18, this volume). In addition, outcome measures of early educational stages (e.g., language abilities acquired in preschool years as indicated by receptive vocabulary and grammar as well as by measures of phonological awareness) can be analyzed with respect to their relative significance to and interrelation with the domain-specific functional competencies assessed (see area B). For area D, but also for special adaptations in area C, it is particularly the expert groups focusing on specific educational stages who are responsible for this.

5.3 Assessment design and outlook

The assessment frequencies of the individual competence domains have been arranged to allow for systematic intra- and interindividual comparisons across ages and cohorts. At each measurement point, a set of competencies will be tested in rather fixed combinations. Taken together, the proposed design plan is guided by two principles: (a) enabling systematic comparisons of participants of the same age but in different educational stages or tracks, and (b) implementing rather fixed intervals between assessment waves, especially for those domains that will be modeled coherently over the life span. These intervals are shorter during lower stages in which greater changes are expected, whereas they become longer in later cohorts.

All in all, the measurement of competencies over the life span is one of the major challenges facing the NEPS. As well as selecting a broad, but nevertheless limited number of competencies to be included in the NEPS, it is important to operationalize these competencies within a coherent framework and to convert them adequately into assessment instruments for all age groups and cohorts. It is essential for these tests to be sensitive to individual change between the measurement cycles if we are to obtain a solid database for monitoring, describing, and analyzing educational processes that will deliver an in-depth understanding of developmental trajectories, their conditions, and their significance for (different) life courses.

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