2 Theoretical Framework

In the first chapter of this theoretical framework, I will address the role of science within education in general. It provides the theoretical foundations for the analyses conducted in this study in light of the question what aspects of science education are considered important for the scientifically literate individual in the society of today and in the near future. By defining related terms and concepts, I will further point out the significance of science education for the individual and society and shed light on purposes and forms of organization of the compulsory years of school science education. Moreover, I will introduce the PROFILES Project both as an example of efforts to enhance science education in Europe and as the framework in which this study has been carried out. In the second chapter, I will discuss the theory of curriculum and curricular dimensions of science education with respect to science education as a curriculum-based, institutionalized endeavour. In the third chapter, I will describe elements of a curricular process and identify central stakeholders of society that are affected by science education. Furthermore, I will introduce the Delphi method as a means to access, collect and structure opinions of a group of stakeholders within a curricular process. In the fourth chapter, I will provide insights into findings of previous science curriculum related Delphi studies in physics, biology, and chemistry. In the fifth chapter, I will present the research questions and hypotheses of this study.

2.1 Science in the Context of General Education

There is widespread recognition that science is an essential part of education (e.g. Gräber & Nentwig, 2002; Hollanders & Soete, 2010; OECD, 1999; UNESCO, 1993). When considering science education in Germany within the broader context of education in general and addressing the importance of science for general education with respect to the overarching ideas of education, some reflections have to be made on concepts of general education with an emphasis on the German theory of education and the German concept of *Allgemeinbildung*. Fundamental to addressing the role of science within mandatory school education is also a clarification of the concept of scientific literacy and a discussion of the purposes of scientific literacy based science education. Moreover, as this study is part of a European endeavor which approaches science education from a holistic perspective, I will discuss the rationale for an integrated perspec-

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tive on science in the context of education and introduce the PROFILES Project is introduced both as an effort to enhance science education in Europe and as the framework in which this endeavor is embedded.

2.1.1 Reflections on Concepts of General Education

Education can be seen as one of the central themes in society (Tenorth, 1986a). General education in terms of students' personal development and their preparedness as citizens in modern society is often linked to the unique German concept of *Allgemeinbildung,* which can very roughly be translated as "general education" or "education for all". The idea of *Allgemeinbildung* traces back to the roots of the European educational tradition and refers to the overarching purposes of education. Having been influenced by different thoughts of educational theory over the time, *Allgemeinbildung* represents a multi-faceted construct with respect to its understanding and interpretation (Benner, 2002; Heymann, van Lück, Meyer, Schulze, & Tenorth, 1990; Klafki, 2000, 2007; Sühl-Strohmenger, 1984; Tenorth, 1986b, 1994, 2003, 2006). In order to shed light on the concept of *Allgemeinbildung*, the following subchapter will clarify the underlying ideas and related terms of this concept.

Within *Allgemeinbildung*, the two terms *allgemein* and *Bildung* can be distinguished. The noun *Bildung*[1] is the term for a key idea in the German theory of education. As there is no precise English translation and a simple translation as education might invoke misleading connotations, the concept of *Bildung* is in English research literature also denoted by paraphrases such as formative education (Vásquez-Levy, 2002), liberal education (Løvlie & Standish, 2002; Westbury, 1995, p. 243), cultivation (Westbury, 1995, p. 234) or as formation of personality through education (Westbury, 2000). Vásquez-Levy (2002, p. 118) underlines that "English must employ several different articulations in order to capture the many aspects of the German expression". She points out that when focusing on the developmental aspects of an individual within a discussion on *Bildung*, one speaks of maturation, whereas the individual's relation to his or her environment are addressed in terms of emancipation. Further facets of meaning are social aspects such as "the capacity to open up to diverse circumstances to extend the concept of humanity through responsible activity" (Vásquez-Levy, 2002, p. 118). With respect to translating the role of education in terms of *Bild-*

1 The discussion of the German term Bildung in this place is meant to consider its meaning and implications with respect to addressing contemporary science education. A detailed elaboration is beyond the scope of this work. Comprehensive accounts are e.g. provided by Klafki (2000, 2007), Tenorth (1986a, 1994, 2003, 2006), von Hentig (1996), and Blankertz (1984).

ung into English, expressions such as the "the ideal of self-determination, the formation of character, or exercise of autonomy, reason and independence" are used (Vásquez-Levy, 2002, p. 118). For an approach to the idea of *Bildung* in English, it has thus to be noted that "[a]ll of these labels and qualities in their English forms are inherent in the German term *Bildung"* (Vásquez-Levy, 2002, p. 118). Therefore, definitions of the term in the English-speaking research community with reference to the variety of facets of the German idea of *Bildung* include descriptions such as "the process of developing a critical consciousness and of character-formation, self-discovery, knowledge in the form of contemplation or insight, an engagement with questions of truth, value and meaning (Vásquez-Levy, 2002, p. 118)". The emancipatory sense of *Bildung* is captured in the meaning of the German verb *bilden* (which can be translated as "to form" or "to shape") (Tenorth, 2006, p. 7). This connotation emphasizes the process of an individual's personal development and is in this way often also related to the concept of action competence (Mogensen & Schnack, 2010) and citizenship (Elmose & Roth, 2005). As the concept of *Bildung* in its original sense is understood in a broader sense than English translations, the German term is used in international research literature as well (Elmose & Roth, 2005; Nijhof, 1990; Sjöström, 2013; Wimmer, 2003).

Bildung and its interpretation as *Allgemeinbildung* became a central focus of reflection around the transition from the 18th to the 19th century, a time that was characterized by the later part of the Enlightenment, philosophical-educational idealism, the classical period of German literature, neo-humanism, and certain undercurrents of Romanticism (Klafki, 2000, p. 85). As the concept of *Bildung* has throughout time been subject to different thoughts and influences of society and cultural contexts, *Bildung* is a dynamic construct that has undergone a variety of shifts with respect to its meaning and interpretation (Klafki, 2000; Tenorth, 1986a). The political-moral connotation of *Bildung*, for example, faded at the end of the 19th century, as *Bildung* became increasingly associated with aesthetic education (Pinar, 2009, p. 27).

With different approaches to a contemporary use of the concept, *Bildung* features a multitude of differentiations. Yet, since the 1970s, *Bildung* has become an increasingly discussed subject of social relevance (Blankertz, 1984; Heymann et al., 1990; Klafki, 2007; Klemm, Rolff, & Tillmann, 1985; Neuner, 1999; OECD, 1999; Sühl-Strohmenger, 1984; Tenorth, 1986a; von Hentig, 1996; Wimmer, 2003). In this context, *Bildung* contains as two major pillars a personal and a social dimension. According to this division, *Bildung* should on the one hand contribute to individual self-development, on the other hand, *Bildung* is also realized in a social context and related to the notion of social responsibility (J. Mayer, 1992, p. 14).

One of the most influential and distinguished scholars with respect to a contemporary understanding of the concept of *Bildung* is the German scholar Wolfgang Klafki, whose works had great impact on educational theory in Germany and beyond. He underlines that in German, *Bildung* means both the process and the product of becoming educated *(gebildet)* with the help of others (Klafki, 1995a, p. 15). Based on the idea of mutual interrelatedness between the individual and the world, Klafki (2000, pp. 91ff.) proposes a dialectical understanding of *Bildung*. He describes *Bildung* in its double meaning as both the world being accessible to the individual (the objective or material aspect) and the individual being accessible to the world (the subjective or formal aspect), which leaves *Bildung* between the two poles of the needs and interests of the individual and the requirements of society. This inextricable link between subjectivity and objectivity in *Bildung* takes place in the relation of the self to the world (Klafki, 2000, p. 91). Hence, according to Klafki (2000, p. 93) self-formation occurs through an engagement with the world so that the cultivation of personal uniqueness and individuality does not occur in isolation but only in communication with others through processes of recognition and mediation. Klafki (1964) links these two components in a categorical concept of *Bildung* that is characterized by the principles of the elementary, the fundamental and the exemplary. For Klafki (2000, pp. 87ff.), an essential feature of *Bildung* is helping students to develop three basic abilities that trace back to the tradition of German education theory: the competences for self-determination, participation in society, and solidarity with others. Moreover, he names responsibility, reason, emancipation, and independence as abilities to achieve through *Bildung*. Describing *Bildung* as embracing all dimensions of human abilities, Klafki's understanding of *Bildung* includes attitudes and skills such as aesthetic awareness, acting in society, the ability to judge and to organize, self-reflection, argumentation skills, empathy, complex reasoning, and a reflective relation towards others and the world a result of the educational process. In this way, *Bildung* can be seen as a mediator between the individual and the world.

Taking into account these considerations, it becomes apparent that the idea of *Bildung* cannot be reduced to fostering reason and rationality. With the notion that society needs educated citizens who are able to make informed decisions (Fleming, 1989; Gräber et al., 2002), the contemporary use of the concept is shaped by the notions that *Bildung* should serve to prepare the students for effective participation in a technologically sophisticated society by enabling them to become responsible and reflective citizens (Fleming, 1989; OECD, 2000). Moreover, the current notion of *Bildung* refers to being part of the constant process of the students' personal formation and socialization throughout the course of which several overarching abilities are enhanced (Klafki, 2000, pp. 85ff.). In general, it can thus be said that *Bildung* has “as its aim the fulfillment of humanity: full development of the capacities and powers of each human individual to questioned preconceived opinions, prejudices, and ‘given facts’, and intentioned participation in the shaping of one’s own and joint living conditions” (Mogensen & Schnack, 2010, p. 61).

Tying in with the notions of the German tradition of *Bildung*, Bolte (2008, p. 332) defines *Bildung* as

> “the idea, necessity, task, process, and endeavour to form one’s own identity and enlightened world view in a self-determined examination of the world; to gain knowledge and abilities in order to find orientation as well as to become capable of acting and judging”.

However, Bolte indicates that self-regulated personality development as rooted in the classical notion of *Bildung* is limited within school education and thus points to Tenorth’s understanding of the concept of *Allgemeinbildung* as

> “[…] all efforts of a society, culture, or nation that serve, by means of societal institutions, to spread that knowledge and those abilities and attitudes among the adolescent generation whose mastery is historically regarded as being necessary and indispensable” (Tenorth, 1994, p. 7, translation following Bolte, 2008, p. 332).

As these efforts are not determined by the students, it can be argued that *Allgemeinbildung* as the central task of school education (Eckebrecht & Schneeweiß, 2003; Heymann, 1990; Schecker et al., 1996; Sühl-Strohmenger, 1984) constitutes a shift from the subjective focus of *Bildung* to *Bildung* being seen as a bundle of associated tasks featuring consensus in contemporary society, and which point to a more functional meaning of *Bildung* (Heymann et al., 1990; Schulze, 1990). In fact, it can be noted that today, there is a dominant understanding of *Bildung*

> “as a central element and instrument to equip the individual with relevant knowledge, competences and skills to cope with the dynamism of societal change and expectations” (Wimmer, 2003, p. 168).

However, concerns are expressed with regard to the understanding of *Bildung* as being solely the attainment of skills and knowledge as a means to promote one’s own interests in global competition (Wimmer, 2003, p. 169).

Klafki (2000, pp. 88ff.) describes the efforts of general education in terms of *Allgemeinbildung* by distinguishing three shades of meaning of the prefix *allgemein*. The first refers to a *Bildung* that is addressed to everyone. The second facet relates to a *Bildung* that takes place in the medium of a general, that is, “of historical objectifications of humanity, of humaneness and its conditions, with an orientation to the possibilities of, and obligation to, humanitarian progress”

(Klafki, 2000, p. 92). By this, Klafki means engaging with common key issues featuring cultural, social, political and personal dimensions. The third aspect refers to the individual's development of versatility embracing all dimensions of human interest, such as cognitive, social and emotional aspects and going beyond the classical canon of education. In this way, *Allgemeinbildung* is not seen as a mosaic of specialized knowledge of academic subjects but rather defined as *Bildung* in a threefold sense.

Relating Tenorth's and Klafki's definitions of *Allgemeinbildung* and referring their understanding of *Allgemeinbildung* to science education, science related *Allgemeinbildung* can be defined from the viewpoint of the German theory of education according to Bolte (2008, p. 332) from the perspective of science as

> "those efforts of general education, which are addressed to all people, contribute to the individual's formation or versatility, and should be promoted in the framework of general global problems"

As the process of *Allgemeinbildung* is closely linked to and fostered through content, the concrete tasks of the different realms of formal education should be reflected in the light of the overarching aims of education (Heymann et al., 1990; Schecker et al., 1996; Tenorth, 1994). According to the theory of *Bildungsgang-didaktik*, which especially takes into account the educational process of the individual (e.g. Meyer & Reinartz, 1998; Schenk, 2005), educational content should in particular refer to developmental tasks (Havighurst, 1981) such as personally relevant challenges of individuals with which they are confronted throughout their lives and within which they develop their personalities.

The authors of a report on how to increase the efficiency of mathematics and science teaching in Germany (Bund-Länder Kommission für Bildungsplanung und Forschungsförderung, 1997) point out that in the German discussion on a modern understanding of *Allgemeinbildung*, attempts have been made to reconcile the pragmatic approach of coping with life by Robinsohn with the values and personality oriented understanding of education by Wilhelm von Humboldt (Gräber, 2002, p.7). In that manner, *Allgemeinbildung* is in particular understood as transcending disciplines, leading to transdisciplinary general competences independent of the particular subjects. The authors emphasize the importance of such general competences for coping with life in present and future, and highlight the basis of these competences for lifelong learning. They identify four areas of general competences (Gräber, 2002, p.7):

- mastery of basic cultural tools such as language and mathematical symbols and routines,
- contextual knowledge in key domains of knowledge,

- metacognitive competences and motivational orientation,
- social-cognitive and social skills.

With respect to educational content that is oriented towards the concept of *Allgemeinbildung*, Tenorth (1994, p. 173) formulates four dimensions featuring consensus for an *Allgemeinbildung* oriented core curriculum: language, the historical-social learning field, the mathematic-scientific learning field, and the aesthetic-expressive learning field. He continues to point out that these learning areas allow for recognizing the world as a communicative unit, to communicate within this world, and to see the problems of the world both as historically grown and as socially processable. At the same time, these structures allow for formulating one's own subjectivity and address reality beyond traditional school subjects.

The following sub-chapter discusses how these considerations relate to the role of science within general education in particular and how science education is embedded in the framework of general education.

2.1.2 The Contribution of Science to General Education

Science shapes our modern culture, impacts our individual and collective lives, and provides both theoretical visions and tangible options to improve human conditions (Ramsey, 1997, p. 325). Thus, it is widely acknowledged that science, independently of cultural or social settings, is one of the fundamental and indispensable dimensions of education in general (DeBoer, 1991; Tenorth, 1994).

The relationship between science and education can be traced back to the introduction of modern science into Western civilization at the end of the 16th century (Hurd, 1998, p. 407) and its advancement during the 17th century within the establishment of natural philosophy as a social institution (Aikenhead, 2003, p. 4). Notwithstanding the classical and humanist educational traditions, notions developed that general education in the sense of *Allgemeinbildung* also takes place and is achieved through engaging with science. It was further emphasized that the study of science serves the understanding of the modern world and that science education should be connected to the student's real world experiences (von Engelhardt, 2010). Special influence on the rationale of science as a part of general education is attributed to thinkers of the Age of Enlightenment such as Francis Bacon (Schöler, 1970, p. 23) who stated in 1620 that

> "the ideal of human service is the ultimate goal of scientific effort, to the end of equipping the intellect for a better and more perfect use of human reason" (Dick, 1955, p. 441 quoted in Hurd, 1998, p. 407).

This demand for science education grounded on the principals of empirical realism also prompted John Amos Comenius in the 17th century to promote the idea of pursuing formal educational goals through engaging with natural phenomena and to put forward an appreciation of science education and efforts towards more equal treatment of the educational value of science among the other traditional subjects (Schöler, 1970, p. 23). Theodor Litt (1959) and Martin Wagenschein (1968, 1980) were pioneers among German speaking thinkers addressing the significance of science for general education. Wagenschein underlined the necessity of science-related *Allgemeinbildung* for those parts of society that do not pursue careers in the field of science (Wagenschein, 1980, p. 11). In this way, humanistic perspectives entered the science curriculum and were described in terms of "values, the nature of science, social aspects of science, and the human character of science revealed through its sociology, history, and philosophy" (Aikenhead, 2003, p. 2).

In Germany, science education first received validity with respect to general institutionalized education and became a regular part of the curriculum of schools of general education with the establishment of the *Realschule* at the beginning of the 18th century (Bonnekoh, 1992, p. 71). A further influential factor for the development of science education in Germany was a greater acceptance of science in the public in the course of economic advancement during the 19th century (Schöler, 1970, p. 72). Thus, towards the end of the 19th century, science was increasingly seen as a fundamental aspect of culture and established as an essential part of the curriculum at schools of general education, both in Germany and beyond (Bonnekoh, 1992, p. 7; DeBoer, 1991, p. 216).

In 1902, Smith defined five potential contributions of science teaching to general education (DeBoer, 1991, p. 54):

1. Training in the powers of observation of the natural world
2. Training in a powerful method of generating new knowledge that is based on observation and experiment
3. Exercise of the imagination and creative impulses
4. Training to view problems objectively
5. Generation of useful information

However, "in the first half of the 20th century, the study of science was linked to effective living in an increasingly industrialized world" (DeBoer, 1991, p. 217). In this manner, the content of science education in school was still mainly dominated by the need to provide the foundations for professional training of future scientists for much of the last century (OECD, 2003, p. 92). This changed with the growing role of science in modern life so that science education was promoted more and more on the basis of its relevance to contemporary life (DeBoer, 1997, p. 73) and "its contribution to a shared understanding of the world on the part of all members of society" (DeBoer, 2000, p. 583). This development was also inspired by early 19th century thinkers such as John Dewey who emphasized that dealing with science enhanced the ability of critical thinking and a scientific attitude embracing aspects such as analyzing, formulating research questions, logical thinking, and relying on solid evidence (Shamos, 2002, p. 45). Dewey described science with respect to its importance for society "as a legitimate intellectual study on the basis of the power it gave individuals to act independently" (DeBoer, 2000, p. 583) and, based on "its practical applications and its focus on the real activities of life" (DeBoer, 1997, p. 72), as a potential link between science teaching and responsible citizenship in democratic societies (Oliver, Jackson, & Chun, 2001, p. 11), pronouncing that

> "[w]hatever natural science may be for the specialist, for educational purposes it is knowledge of the conditions of human action" (Dewey, 1916, p. 228 quoted in DeBoer, 2000, p. 583).

Today, it is widely recognized that scientific competences and knowledge are not just important for contemporary industrial and knowledge-based societies with respect to social progress and in order to compete with scientifically and technologically accomplished professionals on a global market. With the prevalence of the sciences in all realms of life and with every individual's responsibility in the society, a profound science education is also essential for every individual with respect to opinion-making and decision-making skills regarding one's own actions. Moreover, science is counted among the great achievements of modern society, in which a scientific understanding plays an essential role for developing an enlightened world view. Furthermore, with the development of an informed citizenry being one of the main functions of school education, it is indispensable that citizens are able to recognize and understand social issues with scientific references in order to participate in social discourse and policy-making processes (Gräber & Bolte, 1997; Gräber & Nentwig, 2002; Kolstoe, 2000; NRC, 1996; OECD, 2003).

The centrality of science related issues for an individual's education is also reflected in the consideration of scientific literacy (see 2.1.3) as a general ability for life (OECD, 2003, p. 21). Addressing science education within mandatory education, the expert group of PISA underline the significance of science for an individual's acting and managing in everyday life with regard to issues of health, disease, nutrition, sustainability, climate, environment, and consumer behavior (OECD, 2000, p. 79). Likewise, the American Association for the Advancement of Science stresses the task of schools to foster healthy, socially responsible behavior among young people within the context of science education and to prepare them for citizenship, for work, and for coping with everyday life (AAAS, 1990, 1993, 2001). For these reasons, science is seen as a fundamental dimension of general education in school (OECD, 2007b). Therefore, science education must provide a context for general educational goals, providing a basis for meaningful, generalizable learning outcomes for the students as citizens (Ramsey, 1997, p. 325).

Bridging the gap to Klafki's understanding of *Allgemeinbildung* in the sense of *Bildung* for everyone and to the growing role of science in modern life, "the objectives of personal fulfillment, employment and full participation in society" increasingly require that all adults should be scientifically literate, not just those aspiring to a scientific career (OECD, 2003, p. 92). Hence, the 'Science for All' slogan now has global resonance (Jenkins, 1999) and the necessity is underlined for a science education for all that embraces skills of opinion-making, responsibility, critical assessment and acting with regard to nature and technology (AAAS, 1990; Gräber & Bolte, 1997; Gräber et al., 2002).

Dimensions of science through which education in terms of personal formation can be achieved with particular reference to physics education are discussed by Lauterbach (1992a). Recognizing the implications of Klafki's understanding of *Bildung* for physics education, he defines as relevant epistemological dimensions education through scientific knowledge (knowledge about the world), education through knowledge of the theory of science (limits of scientific knowledge and inquiry), education through historical knowledge (social determination), education through self-awareness (construction of reality), education through discursive inquiry (validity as an application problem), and education through impacting knowledge (interaction as dialogue) (Lauterbach, 1992a, pp. 19–33).

The notion of undergoing and achieving education through a preoccupation with science with the education-through-science approach is also a central aspect of the PROFILES Project (see 2.1.5), an FP7 funded European project that aims at enhancing science education by making efforts to disseminate a modern understanding of science teaching, encouraging new approaches into the practice of science teaching and facilitating an uptake of inquiry-based science education (Bolte et al., 2011; Bolte, Holbrook, & Rauch, 2012; Bolte & Streller, 2013; PROFILES, 2010b). Following the constructivist notion of learning as a process in which the individual is actively involved, and thus implying certain ties with Klafki's education theory (Klafki, 2007) and the theory of *Bildungsgangdidaktik* (e.g. Schenk, 2005), the education-through-science approach promotes a focus on the students and proposes that education be the major emphasis, independently of being undertaken within science teaching or teaching in any other discipline. In this way, the students' needs, interests and perspectives are given precedence over subject-propaedeutic demands. Within the PROFILES framework, the education-through-science approach embraces a wide range of educational attributes, such as an appreciation of the important role science plays within the world, recognition of the relevance of education-through-science for lifelong learning, responsible citizenry, and preparing for a profession (Bolte, Streller, et al., 2012, pp. 31–33; Bolte & Streller, 2013, pp. 180–181).

In Germany, the contribution of science to general education is in part of the national education standards specified for the three science subjects biology, chemistry, and physics (KMK, 2005a, 2005b, 2005c). The particular contribution of biology education is related to an involvement with the living world. Living nature is classified and represented by various systems, e.g. cell, organism, ecosystem, biosphere, their interactions and their evolutionary history. An understanding of biological systems requires dynamic thinking and taking different perspectives. This makes it possible to develop multi-perspective and systematic thinking through biology teaching. Moreover, the human being in this system structure is part and counterpart of nature. With the human being as a subject in biology classes, biology teaching contributes to the development of individual self-awareness and emancipatory action. This is the basis for health-conscious and environmentally sustainable action both in individual and in social responsibility (KMK, 2005a, p. 6).

The contribution of an engagement with chemistry to general education lies in the unique properties of chemistry to examine and describe the material world with special reference to chemical reactions as a sum of mass and energy transformation by particle and structural changes and the modification of chemical bonds. In this way, chemistry provides insights into the composition and synthesis of substances and materials, and for dealing with them appropriately. Also, an occupation with chemistry enables students to explain and evaluate phenomena of their environment on the basis of their knowledge of substances and chemical reactions, to make decisions and judgments and to communicate them appropriately. Moreover, dealing with chemistry helps the students to recognize the importance of chemistry as a science, the chemical industry and chemistry-related professions for society, the economy and the environment. At the same time, chemistry makes the students aware of a sustainable use of resources. This includes the responsible use of chemicals and devices in household, laboratory and environment, and safety-conscious experimentation. In addition, the students learn to use the experimental method in particular as a means for individual knowledge acquisition about chemical phenomena and learn about the limits of scientific inquiry (KMK, 2005b, p. 6).

Physics serves as an essential basis for understanding natural phenomena and for the explanation and evaluation of technical systems and developments. With the unique contents and methods of physics, an occupation with physics enhances the subject-specific approaches to tasks and problems as well as the development of a specific worldview. In particular, dealing with physics enables an encounter with the world through the modeling of natural and technical phenomena and predicting the outcomes of cause-effect relationships. In this regard, both a structured and formalized description of phenomena and addressing their essential physical properties and parameters play a role. Thus, by engaging with physics, the students are provided with occasions to use the physical modeling of natural phenomena for explanations. In this way, physics education can provide a basis for young people for an occupation with scientific topics and their social contexts (KMK, 2005c, p. 6). The AAAS pronounces that as the

> "life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics, and technology and to acquire scientific habits of mind; without a scientifically literate population, the outlook for a better world is not promising" (AAAS, 1990).

Hence, today – in Europe and around the world – science is an established part of the curricula of schools of general education with the overall aim of enhancing the students' scientific literacy as part of their general education and serving as a basis for lifelong engagement with science (e.g. OECD, 2007b).

This overall aim of science education to enhance students' scientific literacy is widely agreed on (Bybee, 1997; Eckebrecht & Schneeweiß, 2003; Gräber & Nentwig, 2002; NRC, 1996; OECD, 2000). The term scientific literacy can be translated into German as *naturwissenschaftliche Grundbildung* (Baumert et al., 1999; Gräber & Bolte, 1997; Gräber & Nentwig, 2002; OECD, 2007a; Rost, Senkbeil, Walter, Carstensen, & Prenzel, 2005). *Grundbildung* is a term used in the German-speaking scientific research community that underlines the basic and versatile facet of *Bildung* (e.g. Baumert et al., 1999, 2000, 2000; Gräber & Nentwig, 2002; M. Kremer, 2012; Lauterbach, 1993; Rost et al., 2005). In a more narrow sense, *Grundbildung* can also be attributed to school education at the primary and lower secondary level, referring in this way to those levels usually included in compulsory education (Schulze, 1990).

Within the framework of PISA, three different dimensions of literacy in the sense of *Grundbildung* are operationalized – reading literacy, mathematical literacy and scientific literacy. Similar to the overarching ideas of education, the PISA domains of literacy focus on "the ability to undertake a number of fundamental processes in a range of situations, backed by a broad understanding of key concepts, rather than the possession of specific knowledge" (OECD, 2000, p.

7). In this way, PISA frames the idea of literacy in terms of *Grundbildung* as "the ability to stand apart from arguments, evidence or text, to reflect on these, and to evaluate and criticize claims made" (OECD, 2000, p. 12) and as

> "the capacity of students to apply knowledge and skills in key subject areas and to analyze, reason and communicate effectively as they pose, solve and interpret problems in a variety of situations" (OECD, 2007b, p. 16).

According to this understanding, *Grundbildung* includes facets of analysis, problem solving and communication as well as aspects of evaluation and critical reflection.

The relation of science education to such an understanding of *Grundbildung* is captured in the concept of scientific literacy as the main goal of science related general education. The following chapter addresses the thoughts that the construct of scientific literacy has come to represent and the attempts to define the meaning of scientific literacy as an educational goal within science education.

2.1.3 Scientific Literacy

As scientific literacy represents an essential component of the modern understanding of the aims and objectives of science education (Laugksch, 2000, p. 71), this chapter takes a closer look at the concept of scientific literacy.

The term scientific literacy was introduced by Conant in the 1950s and traces back to a movement in the United States, which, prompted by the postwar drive for industrialization, the Sputnik embarrassment and general dissatisfaction with the outcomes of science education, aimed at a modernization of science education and a reform of the science curriculum to enhance student achievement in science to prepare for more workforce in science and science related professions (Bybee, 1997, 2002; Hurd, 1998). Subsequently, the term was in particular brought into discussion with reference to the need to educate citizens who are able to understand scientific contributions and engage in meaningful democratic participation, representing a step toward building a civic dimension of scientific literacy (Hurd, 1998, p. 408). Since then, the term scientific literacy has over time been subject to continuous change and diversification of its original meaning (Bybee, 1997, 2002).

In the 1960s, tying the goals of science education to societal ideals, scientific literacy was especially characterized by social aspects of science, such as the recognition of the socio-historical development of science, ethical aspects, cultural dimensions and the social responsibility of science (Bybee, 2002, p. 24). Traditionally, only a small group of students had focused on science education in school, which prepared them for future careers associated with science. In response to this, the National Science Foundation recommended in the 1970s that science education should be rethought with more "emphasis on the understanding of science and technology by those who are not and do not expect to be professional scientists and technologists" (Hurd, 1998, p. 409). Thus, it was along with the 'Science for All' approach in the 1970s (Fensham, 1985; Gräber, 2002; Jenkins, 1999) emphasized that "all students should become scientifically literate if they were to deal effectively as adults with […] important social concerns" (DeBoer, 1991, p. 174). In this way, the term scientific literacy became "the watchword of the 1970s" and came to be used to describe "an education in science for all youth that was relevant to their lives and that focused on socially important issues" (DeBoer, 1991, p. 174). The understanding of scientific literacy in the 1970s was thus supplemented with aspects such as the nature of science, concepts and processes of science, values, the connection between science and society, interest in science, and scientific skills (Bybee, 2002, 24). However, as the term lacked precision, it was also used to "describe a wide assortment of educational goals" (DeBoer, 1991, p. 174). Shen (1975, pp. 46–49) conceptualized in the 1970s three different, but not mutually exclusive types of scientific literacy, termed as *practical*, *civic*, and *cultural* scientific literacy. *Practical* scientific literacy refers to the possession of the type of scientific knowledge that can be used to help solve practical problems, whereas *civic* scientific literacy relates to scientific knowledge and understanding that is necessary for informed participation in public life and policy-making. Shen described *cultural* scientific literacy as being motivated by a desire to learn something about science as a major human achievement. In the 1980s, the term scientific literacy was supplemented by aspects referring to scientific and technological processes, research technologies, scientific and technical knowledge, scientific and technical skills and knowledge in personal and social areas, attitudes with respect to science and technology, and the interaction between science, technology and society for technical processes (Bybee, 2002, p. 24). This enhancement came along with the development of science education from an orientation on the disciplines towards a more contextual orientation of science education, opening it up to technological and social issues, which were realized through various approaches of the Science-Technology-Society (STS) movement (Yager, 1993). Later on, a claim for a renewed vision of scientific literacy in view of contemporary issues was formulated (Hurd, 1998, p. 411) and the term scientific literacy has come to refer to a desired general awareness and understanding of science in public (DeBoer, 2000, p. 582).

Based on an emerging emphasis of the relation between science and society, some researchers claim in particular that scientific literacy based science education should focus more strongly on the global and societal dimensions of the applications of science, discussing social issues that contain various points of view, assessments and different options to act (Kolstø, 2001). In this manner, Ramsey (1997, p. 325) states that "citizenship has been and continues to be an ultimate goal of the educational enterprise". Thus, "school should prepare […] people to exercise the rights and responsibilities of citizenship" as part of an established goal of general education from which science education should not be exempted:

> "All students […] will become citizens […] [and] will be consumers of the products and services of science and technology. All will assume and be responsible for the benefits and the risks of scientific and technological knowledge, products, systems, and services. All will be decision-makers concerning matters of science and technology, either willfully via participation in democratic decision-making or apathetically via the lack of such participation" (Ramsey, 1997, p. 325).

Today, the need of scientifically literate citizens and the development of scientific literacy for all has been recognized worldwide (UNESCO, 1993), as scientific literacy matters both at national and international levels as humanity faces major challenges such as providing sufficient water and food for all, controlling diseases, generating sufficient energy and adapting to climate change (United Nations Environment Programme, 2012 quoted in OECD, 2013, p. 3). The OECD (2013, p. 3) emphasize that

> "many of these issues arise, however, at the local level where individuals may be faced with decisions about practices that affect their own health and food supplies, the appropriate use of materials and new technologies, and decisions about energy use".

As pointed out by the European Commission, the solutions to political and ethical challenges involving science and technology "cannot be the subject of informed debate unless young people possess certain scientific awareness" (EC, 1995, p. 28 quoted in OECD, 2013, p. 3). The European Commission emphasizes that this does not mean "turning everyone into a scientific expert, but enabling them to fulfil an enlightened role in making choices which affect their environment and to understand in broad terms the social implications of debates between experts" (OECD, 2013, p. 28). As knowledge of science contributes significantly to individuals' personal, social, and professional lives, scientific literacy is central to a young person's preparedness for life (OECD, 2013, p. 3).

In recent discourse on desired outcomes of science education for all citizens in the sense of scientific literacy, many voices emphasize socio-scientific facets and see scientific literacy as a premise for social participation and citizenship (Jenkins, 1999; Kolstø, 2001; Sadler & Zeidler, 2009). Also, the applicability of scientific knowledge and the development of competences have come more closely into focus (Gräber & Nentwig, 2002, p. 13). Prevailing conceptions of scientific literacy as a basis for lifelong learning stress

> "the development of a general understanding of important concepts and explanatory frameworks of science, of the methods by which science derives evidence to support claims for its knowledge, […] of the strengths and limitations of science in the real world […] [and] value[s] the ability to apply this understanding to real situations involving science in which claims need to be assessed and decisions made" (OECD, 1999, p. 59).

Moreover, the OECD underlines both an appreciation of the contribution of science to society and a reflective approach to science (2006, p. 21).

Though the assumption that only few people will achieve this in practice has been a source of criticism of scientific literacy and thus researches do not unanimously agree on its feasibility (Shamos, 1995, 2002), scientific literacy is considered the main purpose of science education within mandatory education and represents a major goal for science education for students worldwide (e.g. Bybee, 1997; DeBoer, 2000; Dillon, 2009; Eckebrecht & Schneeweiß, 2003; Gräber & Bolte, 1997; Gräber & Nentwig, 2002; Koballa et al., 1997; Laugksch, 2000; Millar & Osborne, 1998; NRC, 1996; OECD, 2000). Thus, reforming the curriculum so that students achieve scientific literacy has been and still is a major undertaking (e.g. Hurd, 1998, p. 411, American Association for the Advancement of Science, 1993. p. 323).

However, a review of research literature shows that the term bears many different meanings in the international science educational discourse, and that there are still a variety of attempts to bring normative clarification to the idea of scientific literacy. In a review of the different facets of scientific literacy, Norris and Phillips (2003, p. 225) present a list of references in what ways scientific literacy is most frequently used in literature. Aspects scientific literacy is used for include:

- knowledge of the substantive content of science and the ability to distinguish science from non-science
- understanding science and its applications
- knowledge of what counts as science
- independence in learning science
- ability to think scientifically
- ability to use scientific knowledge in problem solving
- knowledge needed for intelligent participation in science-based social issues
- understanding the nature of science, including its relationships with culture
- appreciation of and comfort with science, including its wonder and curiosity

- knowledge of the risks and benefits of science
- ability to think critically about science and to deal with scientific expertise

Bybee has provided major contributions to the discourse on scientific literacy (1997, 2002). Assuming that scientific literacy consists of different levels, he postulates a hierarchical model. According to this model, every individual can undergo a development along nominal, functional, conceptual and multidimensional scientific literacy, suggesting a continuous progression of the degree of scientific literacy as a lifelong process instead of a dichotomy. Bybee distinguishes four different levels in this competence model. The first level refers to *nominal scientific literacy*. This level includes a certain familiarity with scientific terms and topics. However, this familiarity is still characterized by a lack of adequacy and a naive understanding of theories. The second level is labeled as *functional scientific literacy*. This level corresponds to a stage in which individuals are able to use and recognize scientific terminology and scientific language in an appropriate way, but confined to a particular requirement or activity and without being aware of the function and meaning of the used vocabulary in its further context. As the third level, Bybee determines *conceptual and procedural scientific literacy.* This level refers to relating information to the conceptual ideas which connect the different disciplines and fields of the sciences. Hence, the focus of this level is on the central ideas that characterize the sciences. In addition, this stage also includes a comprehensive understanding of the processes and the nature of science. The fourth and highest level is *multidimensional scientific literacy*. This level of scientific literacy goes beyond vocabulary, concepts and procedural methods and includes further perspectives of the sciences, such as the history of science, the nature of science, and the role of science in personal life and society. Accomplishing the next level of scientific literacy within Bybee's model is represented by achieving the knowledge, skills and insights that correspond to the different stages. Bybee criticizes that throughout time, the different dimensions have been pronounced in an unbalanced way. He underlines that realizing scientific literacy in educational practice should seek an adequate balance between his proposed levels of scientific literacy instead of an overemphasis of one level (Bybee, 1997, pp. 27ff.; Bybee, 2002, pp. 23ff.).

As pointed out by Streller (2009, p. 18), Schenk has criticized Bybee's model (2007, pp. 85–87). She disapproves of Bybee's proposition that through such predefined competence development, the views of the students are mostly ignored, contradictory to the theory of *Bildungsgangdidaktik* (cf. Schenk, 2005). She criticizes that in such an understanding of scientific literacy, the consideration of *Bildung* as a process in which the students not only acquire knowledge but also develop their own personalities and world views through individual progress seems to be missing. However, Bybee's understanding of scientific literacy has received widespread attention in science educational discourse.

At the international level, Bybee's model is used in PISA as a reference for the assessment of scientific literacy in terms of what 15-year-old students should know and be able to do within appropriate personal, social, and global contexts. The concept of scientific literacy applied in PISA is mostly determined by conceptual and procedural aspects and thus corresponds most closely to Bybee's third level labelled as *conceptual and procedural scientific literacy* (OECD, 1999, p. 60). Based on three broad dimensions – scientific knowledge or concepts, scientific processes, and situations or contexts (OECD, 2000, p. 76), PISA 2000 and 2003 defines scientific literacy as

> „the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity" (OECD, 1999, p. 60, 2004b, p. 133).

This definition underlines the idea that science education should reach beyond the particular subjects and the mastery of specific curriculum content, leading to more general competences of the learners. With those competences being seen as the basis for the applicability of scientific knowledge in real-life contexts, the main focus of scientific literacy in PISA is "the ability to reflect on and use […] scientific knowledge, understanding and skills to achieve personal goals and to participate effectively in society" (OECD, 2000, p.10). Moreover, scientific literacy in PISA 2000 includes an understanding of the methods by which science derives evidence to support claims for scientific knowledge, and of the strengths and limitations of science in the real world (OECD, 2000, p. 12). The definition of scientific literacy in PISA 2006 was extended to include affective aspects (OECD, 2006, pp. 21–22) and describes scientific literacy in terms of four interrelated features that involve an individual's

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

These features of scientific literacy are summarized as

> "the capacity of students to identify scientific issues, explain phenomena scientifically and use scientific evidence as they encounter, interpret, solve and make decisions in life situations involving science and technology" as, "in order to participate fully in today's global economy, students need to be able to solve problems for which there are no clear rule-based solutions and also to communicate complex scientific ideas clearly and persuasively" (OECD, 2007b, p. 33).

PISA 2015 further develops the construct of scientific literacy and defines it in terms of three domain-specific competences that a scientifically literate individual would be expected to display. These include the ability to explain phenomena scientifically (e.g. recognizing, offering and evaluating explanations for a range of natural and technological phenomena), to evaluate and design scientific enquiry (e.g. as describing scientific investigations and proposing ways of addressing questions scientifically) and to interpret data and evidence scientifically (e.g. analyzing and evaluating data, claims and arguments in a variety of representations and drawing appropriate scientific conclusions) (OECD, 2013, p. 7). PISA 2015 indicates what knowledge these competences require besides content knowledge ("knowledge of science") by specifying the PISA 2006 notion of "knowledge about science" more clearly, splitting it into procedural and epistemic knowledge (OECD, 2013, p. 10). In this way, scientific literacy in PISA 2015 involves not only knowledge of the major conceptions and theories of science (content knowledge), but also knowledge of the common procedures and methods associated with scientific inquiry (procedural knowledge), and an understanding of the underlying rationale for these procedures and the justification for their use, i.e. the degree to which such knowledge is justified by evidence or theoretical explanations (epistemic knowledge) (OECD, 2013, p. 11). This understanding is summarized as "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen" (OECD, 2013, p. 7), acknowledging the diverse and multifaceted purposes of science education within compulsory education.

Comparable characteristics are applied by the National Science Teachers Association (1991) or the National Research Council (1996, p. 22):

> "Scientific Literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific liter-

> acy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately."

Further elaboration on the term scientific literacy has been carried out by Roberts (2007). He differentiates between two overarching visions of scientific literacy referred to as Vision I and Vision II. Vision I looks at science itself, i.e. its laws, theories and processes, and thus stresses scientific content knowledge. This vision is emphasized e.g. in *Benchmarks for Science Literacy* (AAAS, 1993) and *Science for All Americans* (AAAS, 1990), which attempt to bring operational meaning to scientific literacy. Vision II, on the other hand, refers to situations with a scientific component and focuses on socio-scientific decision making, a perspective of scientific literacy that is also emphasized in PISA (Bybee & McCrae, 2011, p. 8). With contextually embedded issues, Vision II goes beyond the traditional boundaries of science and features in this way a proximity to social, political, economic and ethical perspectives. Thus,

> "[w]hereas articulations of Vision I [...] look to the discipline of science to define what scientifically literate individuals ought to know and be able to do, Vision II […] looks to situations that present opportunities for individuals to use scientific ideas, processes, and reasoning" (Sadler & Zeidler, 2009, p. 910).

In this way, these visions can at their most extreme been seen as competing interests with respect to the content of the science curriculum (Dillon, 2009, p. 203), covering the spectrum of educating future scientists versus educating future citizens (Bybee & McCrae, 2011, p. 11). However, according to Roberts (2007, p. 11), both visions should be considered for a comprehensive view of scientific literacy in order to achieve a balance between Vision I and Vision II[2].

In the discussions on the term scientific literacy, it becomes apparent that "[s]cientific literacy has become an internationally well-recognized educational slogan, buzzword, catchphrase, and contemporary educational goal" and that there are a variety of ideas subsumed under the concept of scientific literacy (Laugksch, 2000, p. 71). Hence, Millar (2006, p. 1500) concludes that

> "despite the ubiquity of the term "scientific literacy" in current discussions and debates about the science curriculum, its precise meaning is, however, often unclear,

2 Several additional discussions of this concept can be found. Miller (1997) addresses in particular the development scientific literacy in the United States. Coll & Taylor (2009) as well as Walberg and Paik (1997) provide overviews of exploring international perspectives of scientific literacy, and Oelkers (1997) elaborates on defining and justifying scientific literacy for everyone. Eisenhart and her colleagues (1996) explore the ways in which scientific literacy has been defined, justified and operationalized in current proposals for science education reform, and Baumert (1997) discusses the term from a German perspective.

> and the extent of consensus about the practical implications of adopting it as a central aim of the school science curriculum is uncertain".

Osborne also points out that with "a lack of an explicit and consensually agreed articulation" of scientific literacy (Osborne, 2007, p. 174), differences in meanings and interpretations, as a result may, may have given rise to a view that "scientific literacy is an ill-defined and diffuse concept" (Laugksch, 2000, p. 71). Yet, despite this criticism, scientific literacy appears to underpin the curriculum standards of many countries (Dillon, 2009, p. 201). In addition, Gräber (2002, p.7) argues that despite different approaches, the international discussion on scientific literacy includes a lot of common ideas linked to those of general education in terms of *Allgemeinbildung* and similarly tries to overcome the division of subject-specific contextual knowledge and cross-curricular competences.

In conclusion, scientific literacy as the overall aim of science education can be summarized as

> "an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them" (Council of Ministers of Education, Canada, 1997),

representing "a continuum of understanding about the natural and designed world" (Bybee, 1997, p. 63) and the "cognitive capacities for utilizing science/technology information in human affairs and for social and economic progress" (Hurd, 1998, p. 411). In this way, goals of scientific literacy based science education include:

- *to* encourage students at all grade levels to develop a critical sense of wonder and curiosity about scientific and technological endeavors
- to enable students to use science and technology to acquire new knowledge and solve problems, so that they may improve the quality of their own lives and the lives of others
- to prepare students to critically address science-related societal, economic, ethical, and environmental issues
- to provide students with a foundation in science that creates opportunities for them to pursue progressively higher levels of study, that prepares them for science-related occupations, and that engages them in science-related activities appropriate to their interests and abilities
- to develop in students of varying aptitudes and interests a knowledge of the wide variety of careers related to science, technology, and the environment (Council of Ministers of Education, Canada, 1997).

In Germany, aims of science education with respect to enhancing students‘ scientific literacy are also addressed in the national science education standards in terms of defining different competence areas (KMK, 2005a, 2005b, 2005c). The aims of scientific literacy oriented science education are summarized as making scientific phenomena tangible, understanding scientific language, communicating scientific findings, and dealing with specific methods of scientific inquiry and its limitations, an orientation regarding scientific and technical occupations, and providing the foundations for lifelong and professional learning (KMK, 2005a, p. 6).

In general, DeBoer (1991, p. 240) concludes that science education, as all education, should lead to independent self-activity, empowering individuals to think and to act, and providing new ideas, investigative skills that contribute to self-regulation, personal satisfaction, and social responsibility, interconnected knowledge, intellectual skills allowing individuals to work with what is known, and an awareness of the contexts within which that knowledge and those skills apply.

2.1.4 General Science and the Tradition of Subject Differentiation

In all European countries, science education is to varying degrees compulsory throughout primary and secondary education, beginning as one general integrated subject area and taught in this way throughout the entire period of primary education[3]. It intends to foster children's curiosity about their environment by providing them with basic knowledge about the world and by giving them the tools with which they can investigate it (EC, 2011, p. 60). In several countries, this approach is continued for one or two years in lower secondary education, but is split into separate subjects towards the end of lower secondary education[4]. In this way, lower levels of education mostly feature integrated science teaching. Some countries even teach science as one integrated subject all the way through compulsory school[5]. However, in lower secondary education, science teaching is usually split into separate subjects such as biology, chemistry, and physics (EC,

3 Exceptions are Denmark and Finland, where a division into individual subjects begins before the end of primary education (EC, 2011, p. 61).

4 In Belgium (German-speaking part), Bulgaria, Estonia, Spain, France, Malta, Slovenia and Liechtenstein, science teaching is continued as an integrated program at lower secondary education level, but towards the end of this level, science education also takes place through the different science subjects (EC, 2011, p. 61).

5 In six European education systems (Belgium – French and Flemish Communities, Italy, Luxembourg, Iceland, and Norway) science is taught as an integrated subject entirely throughout both primary and lower secondary education levels (EC, 2011, p. 61).

2011, p. 61), which represent the most commonly taught science subjects in European countries (EC, 2011, p. 7). Yet, while dividing science teaching into different subjects, several countries underline the interrelation between biology, chemistry, and physics in order to encourage teachers to teach in interdisciplinary contexts as often as possible (EC, 2011, p. 62). Many countries apply mixed forms of these approaches, particularly for lower secondary education (EC, 2011, p. 61). Thus, on the one hand, there are education systems mostly determined by biology, chemistry, and physics as separate subjects, on the other hand, many education systems feature curricula with an integrated science subject, so that integrated and subject-specific approaches are present in the European countries to varying extents (EC, 2004, p. vii). Beyond Europe, approaches of integrated science education are practiced in countries of the English-speaking world (NRC, 1996; Prenzel, 2010, p. 21). Countries with integrated science education at the lower secondary level usually offer an overarching science subject, bringing together in its curriculum themes and areas of the different science disciplines. Integrated science education is generally subsumed in subjects such as “science”, but labels often include references to “environment and technology” (EC, 2011, p. 62), ”physical, life and earth science“, “science as inquiry“, “science in personal and social perspectives“, “history and nature of science“, and „processes of science“ (Bybee, 2002, pp. 23–24), or are represented by approaches such as “Science–Technology–Society (STS)“ (Yager, 1993). Examples of other terms describing the variety of curricular arrangements and degrees of integration of science in the context of general education include interdisciplinary, transdiciplinary, multidisciplinary and cross-curricular science education (EC, 2011, p. 59; A. Kremer & Stäudel, 1997, pp. 56–57; Labudde, Heitzmann, Heiniger, & Widmer, 2005, p. 103). Following the European Commission (2011, p. 59), the term integrated science education is applied in this work to represent all curriculum arrangements that merge elements from a minimum of two science disciplines.

Many science education researchers trace back the establishment of general science as a subject in school to the general science movement in the United States at the beginning of the 20th century (DeBoer, 1991, p. 87). As pointed out by DeBoer (1991, p. 88),

> “the notion that an education should be well rounded and focused on the single aim of character development led to a number of attempts to create unifying themes to relate two or more areas of the curriculum”.

In this course, general science as a school subject was established with a focus on the interests and the intellectual development of the young adolescents and with respect to science in the context of everyday life (DeBoer, 1991, p. 88).

Later on, during the curriculum movement and the education reforms of the 1950s and 1960s in the United States, which aimed at enhancing student achievement to achieve a larger workforce in science and science related professions, the focus of science education in the Anglo-American world shifted, however, to following a structure-of-the-discipline approach, giving students in science education a sense of the fundamental ideas of a discipline as early as possible (DeBoer, 1991, p. 159), dealing with the nature of scientific research, basic concepts and encouraging students "to think and act like scientists within the structure that was established (DeBoer, 1991, p. 171). Yet, especially since the 1960s, models of general science that focused on the environment, concepts, and processes, received a renaissance in the Anglo-American world (Häußler, 1973, p. 48). On an international level, the development of science education mostly proceeded from an orientation on the disciplines towards context orientation (Gräber, 2002, p. 3).

In Germany, there is a long tradition of subject differentiation of science education, particularly in secondary education (e.g. Riquarts et al., 1994; Riquarts & Wadewitz, 2001). The establishment of different science subjects in school education in Germany dates back to educational reforms during the 19th century, in the course of which instruction in the natural sciences known as *Realienunterricht* became a regular part of the curriculum (Schöler, 1970, p. 156). Its curriculum was mostly based on the science disciplines (Schöler, 1970, p. 150). Throughout the last decades, science education in Germany has been organized in more flexible ways. The debate on the introduction of integrated science education in Germany and the construction of integrated science curricula started as part of the educational reform in 1970 with Anglo-American models of general science entering the German curriculum discussion on science education. First, interdisciplinary approaches and recommendations for integrated science education received massive resistance of the science education research community and of defenders of traditional science education practice who saw integrated science education as a threat to the autonomy of the traditional science subjects biology, chemistry and physics. In this way, the integrated science subject could not be established in the German school system despite the development of teaching materials and concepts and was for many years only realized on side tracks such as project weeks and in the comprehensive school specific subject "science". Only at the end of the 1980s, in the course of an attempt to redefine education with respect to *Allgemeinbildung*, reform initiatives with integrative character regained attention, and ideas were specified and more specifically realized in practice. Both old and new approaches to the integration of science subjects inspired the didactic discussion about a renewal of science education in

Germany in many ways, so that intensified reform initiatives and pilot projects in this field took place (Frey, 1989; A. Kremer & Stäudel, 1997, pp. 52–54).

The Institute for Science Education at the University of Kiel (Institut für Pädagogik der Naturwissenschaften [IPN]) with the *Integrated Science Curriculum* project played an important role in the development of the idea of integrated science education in Germany (Häußler, 1973). This project included the development of basic structures for the design and the implementation of integrated science curricula and made new impacts on the attempt to overcome subject-inherent structural rigidities in science education. As PISA and TIMSS have given new impetus to the discussion of science education in Germany as well, the idea of an integrated science curriculum was taken up and included in the framework curricula by the curriculum committees of several federal states. However, there is still an ongoing debate on the organization of science education in the German science education research community as well as on a European level, both in terms of integration versus subject differentiation and on the question whether scientific literacy is fostered better within the frame of discipline-oriented subjects such as biology, chemistry, and physics, or within an integrated science subject (EC, 2011, p. 59; Labudde & Möller, 2012, p. 15; Prenzel, 2010, p. 21).

The common instructional approach in science education of differentiating according to subjects obtains its legitimacy and its structural organization from disciplinary core areas of specialized contents and their specific sequence to provide systematic and comprehensive access to scientific concepts (Ramsey, 1997, p. 399). Usually, discipline-based science curricula are organized on the basis of the knowledge, methods, structure, and language of the academic disciplines (e.g. AAAS, 2001; KMK, 2005a, 2005b, 2005c). The MNU[6] stresses that although the scientific method forms the common basis of biology, chemistry and physics, each of these disciplines contains its own scientific perspective. These distinct perspectives are expressed on the one hand in subject-specific concepts and terms. On the other hand, despite their similarities with respect to the nature of their world view and the way of inquiry, the three disciplines emphasize different methodical aspects. While physics is characterized by a high degree of mathematical formalization and abstraction, chemistry is distinguished through methods such as working and observing on the particle level and thinking in sub-microscopic models using its own, symbol-oriented scientific language. For biology, characteristic features are the detection of the history of life and the theory of natural selection as an explanatory principle. Subject-specific

6 Deutscher Verein zur Förderung des mathematischen und naturwissenschaftlichen Unterrichts (German Association for the Promotion of Mathematics and Science Education)

differences are thus inherent in the subject-specific concepts, methods and explanations. Hence, the three subjects do not look at the world through the same "lenses" but consider different strands of the scientific interpretation of the world (MNU, 2003, p. 10). In this way, certain reservations are expressed with respect to realizing approaches of integrated science education.

General concerns towards integrated science education focus on the lack of empirical evidence for the positive impact of this approach on the students' motivation and their performance. Some researchers argue that students might gain a less basic and conceptual understanding in integrated science education, as certain discipline-specific topics are covered in a less detailed way or not at all. Another critical aspect when considering integrated approaches are the teachers' skills and content knowledge, as teachers are usually educated in a limited number of academic disciplines and might feel uncomfortable with the integration of disciplines into their teaching for which they are not trained or qualified (EC, 2011, p. 60). Further objections refer to the difficulty of achieving discipline-specific goals within integrated science, the complexity of interdisciplinary themes and resulting difficulties in their consideration, the preference of biological topics, and the risk of a reduction of the number of science lessons (Labudde & Möller, 2012, p. 15).

On the other hand, it is often criticized that school science is usually fragmented into different strictly isolated disciplines, and it is claimed that science education is in this way failing to provide students with a coherent picture (Christidou, 2011, p. 146). More specifically, it is argued that a division into disciplines is too compartmentalized and hence counterproductive to serve the general education needs of students (AAAS, 2001, p. 86). Also, some researchers claim that despite carrying their own special features, the science disciplines share significant epistemological, conceptual and methodological similarities with respect to scientific thinking and working (Prenzel, 2010, p. 22). Thus, these scholars claim that scientific literacy based science education needs to transcend the familiar perspective of discipline-based school science (Deng, 2007, p. 136).

From a European perspective, two lines of argument are proposed. First, integration in science education seems to correspond to a "common sense", since knowledge and experience are not divided into different compartments in real life either. This claim emphasizes that the traditional discipline boundaries do not meet contemporary requirements and that scientific research itself is becoming increasingly integrated and intertwined so that education in different science disciplines cannot be undertaken well in isolation from the others. The second line of argument focuses on the process of knowledge construction. The teaching of science in a holistic approach and making connections between the different disciplines is considered as a process leading to new ways of thinking that links various abilities, enhances critical thinking and allows for a deeper understanding of scientific issues (EC, 2011, p. 59). Further frequently expressed arguments include the assumption that students' pre-concepts are not formed within discipline structures, possibilities of project-oriented science learning, the promotion of transdisciplinary competences, and the development of students' willingness to engage – in line with Klafki's education theory (see 2.1.1) – with epoch-typical key problems of humanity (Labudde & Möller, 2012, p. 15). These arguments with respect to interdisciplinary approaches of science education are often related to scientific literacy (e.g. Bauer, 1992, p. 113; Gräber, 2002, p. 7).

In Germany, general thoughts supporting integrated science education are expressed in similar ways. It is claimed that furthering scientific literacy within mandatory school education does not require an exact representation of the science disciplines in school or a transition of a simplified version of different science disciplines into school, as this is a misinterpretation of the relationship between academic disciplines and school subjects (Klafki, 1995b, p. 194). Rather, enhancing scientific literacy in school demands an intensive consideration of the real-life contexts of the students, consulting science with respect to its potential and limitations for solving real-life issues (Frey, 1974, p. 16; A. Kremer & Stäudel, 1997, p. 57). Therefore, it is crucial to temporarily neglect traditional structures of the subjects and reveal new relations and linkages instead. In this manner, it is emphasized that a strict division of science education into different science subjects does not reflect reality and is thus an artificial construct that would lead to narrow-mindedness and isolated considerations of scientific issues (A. Kremer & Stäudel, 1997, p. 57). Schaefer (2010a, p. 11) moreover argues that when considering general abilities with respect to *Allgemeinbildung*, only certain parts of science related abilities are subject-specific, whereas a significant part of such abilities is of more overarching nature.

One example of realizing integrated science education in Germany within general education which gives new impetus to the underlying ideas of integrated science education in Germany is the PING project (*Praxis integrierter naturwissenschaftlicher Grundbildung – Practising Integration in Science Education*) (Bünder, 1997; Lauterbach, 1992b, 1993). The PING project was developed in 1989 at the Institute for Science Education at the University of Kiel (Institut für Pädagogik der Naturwissenschaften [IPN]) and is an integrated science curriculum for the development of scientific literacy within general education for grades 5-10. It aims at a balance between systematic science learning within subject-differentiation and real-life-oriented approaches, bringing together seemingly distinct realms and addressing problem-based themes from the different science subjects in an interdisciplinary way through action-oriented approaches of science teaching (Bünder, 1997, pp. 399–400; Lauterbach, 1993, pp. 244–246), following the tradition of Anglo-American integrated science approaches of the 1970s (A. Kremer & Stäudel, 1997, p. 55). PING is based on the assumption that science education takes place in the reflected relation of the individual to nature, other people, culture, and to him or herself. The overall basis of PING is the relationship between the individual and nature. In particular, this includes aspects such as methods of recognizing, treating, and interacting with nature and technology, the comparison of different views, applications of common principles and concepts, and the coordination of discipline-based terms. PING addresses these aspects through age-appropriate themes that are developed with respect to the real-life experiences of the students (Lauterbach, 1993, pp. 244–247). Through its design and conceptual structure, PING also reflects and contributes to the basic ideas of an education for all in the sense of Klafki's understanding of *Bildung* (Lauterbach, 1993, pp. 244ff.).

What generally distinguishes an integrated science curriculum from subject differentiated science teaching is that other elements than the disciplines determine how the content will be organized – elements such as natural phenomena, social and environmental issues, or other cross-cutting themes. However, this does not mean that discipline-based curricula necessarily neglect certain issues or that integrated curricula disregard knowledge and methods from the disciplines. Principally, the same set of specific educational goals could be pursued within either form of organization (AAAS, 2001, p. 87).

Often, controversies about integrated versus subject based science are based on an oversimplified comparison between a school science subject and the corresponding disciplines (Prenzel, 2010, pp. 22–23). In fact, the science disciplines in school are constituted within a reference frame of content and problems coordinated, matched and oriented towards educational goals – not necessarily reflecting the structure of the corresponding science disciplines, which are limited to pursuing scientific goals. Prenzel further points out that in schools of general education, the traditional science subjects indeed provide a necessary requirement for systematic knowledge acquisition regarding the current state of science, but this premise is not sufficient for the universally demanded general education, which schools of compulsory education are obliged to. Hence, Prenzel concludes that adjusting, limiting, and reflecting on learning contents, and also transcending subject boundaries should always take place with respect to the targeted educational goals. It is crucial that students become primarily familiar with the basic issues, concepts, terms and theoretical and methodological approaches of science and understand the special features of each disciplinary perspective. The characteristic features of the scientific disciplines can be made obvious by including an integrative perspective, and considering phenomena and problems from different perspectives. For that reason, an integrated perspective on science should include the disciplinary approaches and perspectives and ensure the development of several competences at the same time. In this way, Prenzel points out that in the case of subject-differentiation, the science subjects in school still have to fulfill a mutual supply function, which requires at least curricular coordination and linkages between the science subjects.

2.1.5 Enhancing Science Education in Europe – The PROFILES Project

On the basis of overtly expressed concerns that science education in school is widely perceived as irrelevant and difficult, the European Commission funds projects to increase "students' interest and attainments levels while at the same time stimulating teacher motivation" in the European Commission's 7th Framework Program (EC, 2007, p. 2). This general framework encompasses education-oriented investigations and supports actions that aim at improving the level of scientific literacy in young people.

PROFILES ("Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science") is one of several inquiry-based science projects funded by the 7th Framework Program of the European Commission in the field of science and society. The consortium of the PROFILES Project involves 22 partner institutions from 21 different European or Europe-associated countries, including Freie Universität Berlin (Germany), University of Tartu (Estonia), Weizmann Institute of Science (Israel), Universität Klagenfurt (Austria), Cyprus University of Technology (Cyprus), Masaryk University (Czech Republic), University of Eastern Finland (Finland), University College Cork (Ireland), Universita Politecnica delle Marche (Italy), University of Latvia (Latvia), Maria Curie-Sklodowska University (Poland), University of Porto (Portugal), Valahia University of Targoviste (Romania), University of Ljubljan (Slovenia), University of Valladolid (Spain), Fachhochschule Nordwestschweiz (Switzerland), Dokuz Eylül University (Turkey), Universität Bremen (Germany), ICASE[7] (UK), Karlstad University (Sweden), University of Copenhagen (Denmark), and Ilia State University (Georgia). The project is coordinated by the Department of Chemistry Education at Freie Universität Berlin (Bolte, Streller, et al., 2012; PROFILES, 2010b).

The overall focus of PROFILES is "the promotion and dissemination of IBSE[8] through innovative learning environments and (long-term) teacher training courses to raise self-efficacy of the participating science teachers to take owner-

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ship of more effective ways of teaching to foster students gains – supported by stakeholders" (PROFILES, 2010b). On this basis, PROFILES aims at disseminating a modern understanding of scientific literacy and encouraging new approaches to the practice of science teaching, following an education-through-science approach. Central ideas of science education in the education-through-science approach of PROFILES include an orientation towards the needs and interests of the students, following an IBSE-approach and strong emphasis on scientific inquiry. It takes up themes from real-live contexts, addressing age-appropriately central concepts of science, subject-transcending themes, taking into account the competence areas of the national education standards in a balanced way, guiding students to reflected and appropriate judgment, and aiming at intrinsically motivated learning beyond science lessons (PROFILES, 2010b).

To attain these aims, the project is composed of eight interrelated work packages that address the different aspects of the project. With work package 3 (WP3), which focuses on stakeholder involvement and interaction, PROFILES gives emphasis to examining the views of different stakeholders from science education related areas, asking for their perspectives on what aspects of science education they consider as relevant for the scientific literate individual as a member of society. The significance and relevance of investigating such views is underlined by the fact that the theme of science and society represents a central pillar in the seventh Framework Program by the European Commission. The context of PROFILES allows for collecting the views and opinions of such stakeholders from 21 countries (Bolte et al., 2011; Bolte, Streller, et al., 2012). The stakeholders' views are collected by means of the Delphi method, a tool of group discussion which provides a systematic approach to involving a wide range of stakeholders and bringing together views and opinions from various perspectives in a collective decision making process (see 2.3.3). Within work package 3, this endeavor is carried out in the context of the International PROFILES Curricular Delphi Study on Science Education, which involves in the PROFILES partners' various stakeholders in their countries who are particularly affected by curricular aspects of science education. Such stakeholders are represented by students, science teachers (including science education students at university, trainee science teachers, science teachers and trainee science teacher educators), science education researchers, scientists, and actors in education policy and administration.

The aim of the International PROFILES Curricular Delphi Study on Science Education is to engage these stakeholders in reflecting on contexts, contents and aims of science education and to identify in this way aspects of modern science education that are considered relevant, meaningful, and desirable for the scientifically literate individual of today and in the near future. By applying the Delphi method, this study systematically collects and investigates in three consecutive rounds the views and opinions of different stakeholders. Planned and carried out in the context of PROFILES, the International PROFILES Curricular Delphi Study on Science Education consists of several national curricular Delphi studies being conducted independently from each other by the PROFILES consortium partners in their countries. This provides the opportunity not only to investigate the stakeholders' views on a national level, as done within this study, the Berlin Curricular Delphi Study in Science (Bolte & Schulte, 2014a, 2014b; Schulte & Bolte, 2012, 2013a, 2013b). Furthermore, the framework of PROFILES also allows for identifying similarities and differences between the opinions of stakeholders from different countries (Bolte & Schulte, 2014a, 2014b, 2014c; Gauckler, Bolte, & Schulte, in press; Gauckler, Schulte, & Bolte, 2014; Schulte, Bolte, et al., 2014; Schulte & Bolte, 2012, 2013a, 2014b; Schulte, Georgiu, Kyza, & Bolte, 2014), holding out prospects for insights into a common European perspective on science education as well. Within PROFILES, taking into account these different stakeholders' views and opinions also provides the opportunity to enhance the development of learning and teaching materials and the preparation of teachers' CPD[9] programs as well as to bridge the gap between the science education research community, science teachers and other local actors, allowing for a stronger cooperation between the different stakeholder groups. In this manner, the stakeholders in PROFILES – involved through the International PROFILES Curricular Delphi Study on Science Education – can be seen as partners in the development, evaluation and dissemination of the projects activities and outcomes as well (Bolte et al., 2011; Bolte, Streller, et al., 2012).

2.1.6 Summary

As pointed out at the beginning of this chapter, a need for science education was expressed along with the emergence of science as a definable style of inquiry (Oliver et al., 2001, p. 4). During the 19th century, science was thus increasingly established as part of the curricula of schools of general education (DeBoer, 2000, p. 583; Schöler, 1970, p. 9). On the basis of recognizing the contribution of science to education in general (cf. von Engelhardt, 2010), this development took place in the course of a growing notion of the practical importance of science in a world becoming increasingly dominated by science. This development was triggered by recognizing the importance of the inductive process of observing the natural world, drawing conclusions from it, carrying out independent

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inquiries and investigations in the laboratory, developing an attitude of independence from arbitrary authority, and participating more fully and effectively in an open democratic society (DeBoer, 2000, p. 583).

Today, science is a fundamental and indispensable dimension of education in general, as science education is recognized to contribute to the individual's ability to actively partake in society and opinion-making with respect to science related issues. The central place of science in the school curriculum of mandatory education is also justified by the enormous impacts of science and scientific ideas on our everyday lives and culture. Therefore, in most European countries, science education takes place within the frame of general and common shared educational goals, such as developing the students, both individually and socially, and developing competences, knowledge, skills and attitudes that are deemed to be important for future citizens by each country (EC, 2004, p. vii).

The scientific perspective as an essential component of *Allgemeinbildung* is captured in the concept of scientific literacy, which is considered the main and overarching aim of science education. In German, scientific literacy is translated as *naturwissenschaftliche Grundbildung* and can be defined as a combination of overarching and science-related attitudes and competences.

Common features and aims of a science education with an emphasis on scientific literacy include the process of interaction with and reflection of the world, discovering throughout this interaction one's own role in society, culture and nature, being prepared to act in reflective and responsible ways, and being able to actively partake in social discourse and opinion-making. It is also argued that "the development of positive attitudes and the stimulation of curiosity […] are as important as the development of the conceptual understanding of the subjects" (EC, 2004, viii). Chemistry, biology, and physics represent predominant areas of school science as a regular part of the curriculum. In contrast, with respect to enhancing students' scientific literacy, integrated science education underlines a perspective on science as a comprehensive and interdisciplinary endeavor.

An example of efforts to improve science education and to promote students' scientific literacy through an education-through-science approach is represented by the European PROFILES project.

2.2 Science Education and Curriculum

In the first part of this chapter, I will introduce the concept of curriculum. It will be defined with respect to the purpose of this study. Furthermore, I will discuss the concept of curriculum theory with reference to the German tradition of *Didaktik*. Following these considerations, I will describe different curricular dimensions of science education.

2.2.1 The Concept of Curriculum

Due to the essential role of instruction and teaching in education, curricular matters are central topics of concern in society (Pinar, 2009, p.33). In Germany, the topic of curriculum particularly entered the discussion with reference to scientific literacy after the outcomes of international comparisons such as PISA (e.g. OECD, 2000, 2004a) and TIMSS (e.g. Baumert et al., 2000) and the subsequent debate on the poor performance of the German students.

In general, the term curriculum covers a broad range of meanings, referring to a general sketch of what should happen in schools and to the conditions of learning as well as denoting the students' actual day-by-day experiences. Moreover,

> "papers in the journals speak of a "planned" curriculum, which is different from the 'taught' curriculum (the instruction actually delivered to students), which differs from the 'learned' curriculum (what students actually learn)".

Overall, curriculum is thus often understood in all of its meanings – as it is planned by teachers and administrators, delivered by the teachers, and experienced by the students, as an overview of the scope and sequence of student experiences, and as a detailed delineation of learning experiences (AAAS, 1993, p. 318).

The roots of curriculum theory can be traced back to Comenius (Schaller, 1995, p. 57), who is said to have established the first curriculum of modernity that became a guideline for the following centuries (Gundem, 1995, p. 46). In 1952, Weniger (1952 quoted in Westbury, 1995, p. 241) described the task of the curriculum as "to establish the goals of education, and to select and concentrate what used to be called instructional material". In this way, the term curriculum was originally used to generally refer to the progress of educational measures as well as to learning objectives (Frey, 1970, p. 15). In Anglo-American terminology, curriculum relates to aims, measures, forms of organization and objects that appear in the context of teaching (cf. Posner, 1995). Yet, curriculum is not to be understood synonymously with the teaching process (Frey, 1970, p. 14).

When addressing the term curriculum, two different traditions of approaching curricular matters have to be mentioned – the German tradition of *Didaktik* and Anglo-American curriculum theory (Hopmann & Riquarts, 1995b, p. 9). In Germany, curricular thought has been closely linked to the tradition of *Didaktik.* American curriculum theory only entered the academic discussion in Germany in the 1960s (Hopmann & Riquarts, 1995b, p. 21). Taking account of the complexity that has taken place with respect to the development of these traditions (Hopmann & Riquarts, 1995b, p. 11), Hopmann and Riquarts (1995b, p. 9) state that "both attitudes exist in such a variety of forms that neither can easily be reduced to a single pattern". Yet, in spite of this variety, they argue that each side operates with certain common presuppositions about the relationship between curriculum and instruction. Differences between these approaches refer to several aspects at the level of lesson planning as well as at the level of research and theory (Hopmann & Riquarts, 1995b, p. 26; Westbury, 1995, p. 233), with *Didaktik* being primarily concerned with instruction itself, while curriculum mainly covers aspects such as study plan, school books, instruction concepts etc. (Hopmann & Riquarts, 1995b, p. 21).

However, other scholars in the field of *Didaktik* and curriculum research do not share the view that there are substantial differences between *Didaktik* and curriculum or curriculum theory in Anglo-American usage. For example, Klafki (1995, p. 187) points out that a comparison between attempts to define *Didaktik* and corresponding attempts to define curriculum theory reveals large overlaps, as they are concerned with a parallel set of issues[10].

With the German curriculum discussion of the 1970s and 1980s not systematically distinguishing between *Didaktik* and curriculum research (Hopmann & Riquarts, 1995b, p. 20), Frey describes the term curriculum as the representation of education over a certain period of time in terms of a consistent system with multiple areas for purposes of planning and optimal realization of instruction (1970, p. 15). In addition, Frey (1980b, pp. 21–22) distinguishes between two approaches to the concept of curriculum; a restricted term and a comprehensive term. The restricted term of curriculum essentially means the preparation of teaching, a syllabus or another offer of means that can lead to an educational process. In this understanding, a curriculum is a disposition for a planned educational process and includes all conditions that lead to this process. Thus, the curricular process begins with the first decision or establishment of conditions for an educational process. How the process should be designed is described in this approach, for example, by naming learning goals and objectives. The second, more comprehensive term extends the meaning of the restricted definition by including the realization of the curriculum and its impact. In this way, the term curriculum is also compared to a social process. In addition, the more comprehensive term includes further aspects with respect to the methodology of curriculum development. Hence, Frey (1980a, p. 23, translation following Hopmann & Riquarts, 1995b, p. 20) describes curriculum as the answer to

10 As it is beyond the aim of this chapter to trace the dialogue between Didaktik and curriculum theory in a more comprehensive scope, the discussion on differences is not elaborated on in more detail. Further insights into the dialog between Didaktik and curriculum theory are provided by Hopmann and Riquarts (1995a).

> "how can learning situations be developed, implemented and evaluated, which in the horizon of their societal and objective environment and of the individual self-interpretation of the learners are justified and at the same time optimally guarantee the self-development of all concerned […] before, during and after the envisaged learning process?".

A central element in this approach is curricular justification. According to the work of Frey (1980b, p. 23), justification in a curricular context refers to developing a claim of validity, which is constituted both by theoretical reflections and through involving appropriate stakeholders (see 2.3.2).

Following Frey (1980b, p. 22), this study employs the term curriculum both in its restricted and comprehensive sense. Hence, one product of this study could be seen as a framework for science education providing aspects that the scientifically literate individual should deal with within his or her process of education. Thus, this study leads to science curriculum related features that could serve as a basis and orientation for further realization of scientific literacy based science education. On the other hand, this study also provides insights with regard to curriculum development in the sense of the comprehensive understanding of the concept of curriculum.

2.2.2 Curriculum Elements of Science Education

It is widely recognized that within the context of education, the issue of curriculum content is a fundamental one (Phillips & Siegel, 2013). This notion relates to an argument by Klafki (2000, p. 90), who claims that despite the complexity of the concept of *Bildung*, the implicit questions dominating the reflections on the content of *Bildung* remain the same:

> "What objectifications of human history seem best suited to open a person who is engaged in his or her own *Bildung* […] to the possibilities and duties of an existence in humanity?"

With respect to the relationship between the process of *Bildung* and curriculum, educational content should also be determined at the level of frameworks such as guidelines and curricula besides the level of decisions in instruction of individual schools and teachers (Klafki, 1995b, p. 194). Hence, the question must be asked what attitudes, insights, knowledge, and abilities young people require in order to be able to develop their capacity for self-determination, co-determination and solidarity in their present and future lives. In this way, curriculum design involves a variety of aspects that need to be considered.

As "education for scientific literacy is not a new goal, but one that has come into prominence globally through major curriculum initiatives" (Ratcliffe &

Millar, 2009, p. 946), a number of authors “have attempted to clarify the curricular orientation and instructional emphasis of scientific literacy as a purpose of science education” (Bybee, McCrae, & Laurie, 2009, p. 866). Thus, several curricular movements, designed to promote scientific literacy, have emerged in the field of science education. These include, for example, the Science-Technology-Society movement and related efforts promoted under slogans such as public understanding of science, humanistic science education, context-based science education, and socio-scientific issues, continuing what is described as progressive science education (Sadler & Zeidler, 2009, p. 910). In *Designs for Science Literacy* (AAAS, 2001), scientific literacy is described as a curricular vision that is ”used to convey the normative, ideological basis for determining the subject matter of school science” (Deng, 2007, p. 135) and which has “significant implications for the choice of curriculum content and the way it is structured” (Ratcliffe & Millar, 2009, p. 946).

However, with respect to the question what in particular should constitute the subject matter of the school curriculum for scientific literacy, it is indicated that although definitions of scientific literacy abound in literature and scientific literacy has widely been accepted as a central goal of school science education in the 21st century (cf. 1.3.1), there is no consensus about what the curricular implications of scientific literacy are (Deng, 2007, p. 134). In fact, with scientific literacy being characterized in terms of attributes such as knowledge, skills, and dispositions of a scientifically literate person, or types of literacy involved, there are various definitions capturing the rich meanings of scientific literacy as an educational goal. Nonetheless, they convey very little about the meaning of scientific literacy as an educational goal as it is translated into curricular structures and into classroom practice. Hence, the meaning of scientific literacy should be investigated more closely from the curriculum perspective as well (Deng, 2007, p. 134). According to Ratcliffe and Millar (2009, p. 946), there is at least some agreement that scientific literacy involves three identifiable strands when it comes to considering scientific literacy as a curriculum aim: science concepts and ideas, processes of scientific enquiry, and the role of science in the social context.

Following the approach of Häußler et al. (1980), curricular dimensions of desirable science education can be specified within contexts and situations, topics and concepts, and competences and attitudes. This classification is based on the assumption that generally, all life situations, appearances and actions related to science can be educationally relevant (Häußler et al., 1980, p. 50). On a broader level, this approach can be related to the work of Robinsohn (1975, p. 45), who defines the task of curriculum research as the identification of skills that serve to cope with life situations and the identification of educational content that supports the enhancement of such qualifications. Similar classifications of curricular dimensions of science education can also be derived from the PISA 2006 definition of scientific literacy (OECD, 2006, p. 25), which is characterized as consisting of four interrelated components representing different scientific contexts, contents, competences, and attitudes. The classification of these components is based on the question "[w]hat is it important for citizens to know, value, and be able to do in situations involving science and technology?" (OECD, 2006, p. 20).

As the overarching aim of this study is to identify aspects of science education that are considered desirable and meaningful for students to achieve scientific literacy, the following chapters will discuss contexts and situations, topics and concepts, and competences and attitudes as specifications of curricular aspects of science education.

2.2.2.1 Contexts and Situations

There is growing recognition of the significance of contexts in science education (e.g. Elster, 2007). The notion of contexts as the starting point for the development of a scientific understanding in science education dates back to the early 1980s (Bennett & Lubben, 2006, p. 999; Fensham, 2009, p. 884) and is closely related to achieving overall aims of science education (Waddington, 2005, p. 306), as contexts also allow for addressing aspects of scientific literacy that are not subject-specific (Häußler et al., 1980, p. 50). In particular, embedding science teaching in contexts is seen as a potential way of improving student motivation and interest (EC, 2011, p. 64; Millar, 2005, p. 325) and as effective in enhancing students' scientific literacy (e.g. Council of Ministers of Education, Canada, 1997; Deng, 2007, p. 136). The Canadian *Common Framework of Science Learning Outcomes* (Council of Ministers of Education, Canada, 1997) emphasizes that the development of scientific literacy is supported by meaningful instructional contexts that engage students in active inquiry, problem solving and decision making, as it is through such contexts that students discover the significance of science in their lives and come to appreciate the interrelated nature of science, technology, society, and environment. In this way, contexts are essential to student learning (Finkelstein, 2005, quoted in Gilbert, 2006, p. 970).

Originating from the Latin verb "contextere" ("to weave together"), the related noun "contextus" expresses "coherence", "connection", and/or "relationship". Thus, the general function of "context" is to describe circumstances that provide meaning (Gilbert, 2006, p. 960). According to Duranti and Goodwin (1992, pp. 6–8, quoted in Gilbert, 2006, p. 961), an educational context can be described to feature four attributes. These relate to the framework of a certain event or general phenomenon (setting), actions and measures (behavioral environment), terminology and language framework (language), and background (knowledge).

As context can have several meanings (Whitelegg & Parry, 1999, p. 68), in many cases the term situation is used instead or in addition to context (e.g. Baumert et al., 1999, p. 4). Following Kortland (2011, p. 5), the particular purpose of contexts in science education is

> "to embed science knowledge in a collection of practical situations […] showing, first of all, that science relates to everyday life and enables us to understand practical applications and socio-scientific issues, and, secondly, that science content has a personal and/or social relevance in enabling thoughtful decision making about everyday life behavior".

Thus, contexts, situations – and motives as a related term – can be retrieved from a variety of areas such as nature, leisure, politics, science, consumption, household, public, world view, and culture (Hoffmann & Rost, 1980, p. 65). Typically, they include social, economic, environmental, technological and industrial applications of science and are selected on the basis of their relevance to students' everyday life (Bennett, Gräsel, Parchmann, & Waddington, 2005, p. 1523).

Although the selection of particular contexts may vary, it is recommended that the overall scope and focus of instructional contexts in science education should include three broad areas of emphasis to provide potential starting points for engaging in an area of study (Council of Ministers of Education, Canada, 1997):

- scientific inquiry, in which students address questions about the nature of things, involving broad exploration as well as focused investigations
- problem-solving, in which students seek answers to practical problems requiring the application of their science knowledge in new ways
- decision-making, in which students identify questions or issues and pursue science knowledge that will inform the question or issue

In Europe, it is also suggested that science education processes should be embedded in contexts. Usually, this involves a relation to social and real-life contexts or situations that students are likely to encounter as citizens, such as contemporary societal problems, environmental concerns, the application of scientific achievements, and knowledge to everyday life as starting points for the development of scientific ideas (EC, 2011, p. 9). In this way, recommend contextual issues that teachers should address in science education at primary and lower secondary level in several European countries include, for example, "science and the environment/sustainability", "science and everyday technology", "science and the human body", "science and ethics", "embedding science into its social/cultural context", "history of science", and "philosophy of science" (Eurydice, 2011, p. 66). As

> "[m]odern definitions of […] scientific literacy similarly emphasize the importance of recognizing and understanding the contexts in which [...] science operate[s] and the forces that shape these fields of human activity" (OECD, 2000, p. 15),

situations and contexts represent the third aspect of scientific literacy in the PISA 2000 framework, besides processes and concepts (Baumert et al., 1999, p. 4). Real-life related situations in PISA 2000 are classified into problems that can affect people as individuals (personal level, such as food and energy consumption), as members of a local community (public level, such as drinking water treatment or search for power plant sites) or as citizens of the world (global level, such as global warming, loss of biodiversity). Additionally, situations within the framework of PISA 2000 relate to the advancement of scientific knowledge and the influence of this knowledge to societal decisions (historical relevance) (Baumert et al., 1999, p. 8). PISA identifies "science in life and health", "science in earth and environment", and "science in technology" as three main context areas relevant for scientific literacy (OECD, 2006, pp.12-25, see also Bybee, Fensham, & Laurie, 2009; Bybee & McCrae, 2011; Drechsel, Carstensen, & Prenzel, 2011). These contexts are specified within five sets of life situations: "health", "natural resources", "environment", "hazards", and "frontiers of science and technology", which are, as in PISA 2000, further divided into personal, social or global settings (OECD, 2006, pp. 26–27). Fensham (2009, p. 893) underlines that such contexts are rarely mono-disciplinary, but provide starting points for both single subject and integrated science teaching. Sadler (2004, p. 523) describes contexts that

> "encourage personal connections between students and the issues discussed, explicitly address the value of justifying claims and expose the importance of attending to contradictory opinions"

as most valuable contexts in terms of starting points for learning processes of and about science.

In Germany, projects such as biology in context (cf. Bayrhuber et al., 2007), chemistry in context (cf. King, 2012; Parchmann et al., 2006) and physics in context (cf. Duit & Mikelskis-Seifert, 2010) provide particular contributions on the discussion about how meaningful science education can succeed by embedding scientific concepts, methods and knowledge in contexts that support the students in developing and enhancing their competences.

2.2.2.2 Concepts and Topics

The validity of the justification regarding the inclusion of particular content in educational is a fundamental issue with respect to curriculum development (Phillips & Siegel, 2013). Hence, several attempts have been made to address the issue of relevant teaching and learning content for enhancing students' scientific literacy (e.g. AAAS, 1990, 1993, 2001). PISA 2000 defines scientific concepts from different content areas as fundamental with respect to scientific literacy (OECD, 2000, p. 75). According to the PISA approach to scientific literacy, concepts in science education enable students to give meaning to new experiences as they relate them with what they already know and support students to understand aspects of the natural and man-made world. PISA determines the selection of scientific concepts according to their relevance for everyday life situations, sustainable meaning in the future of the students as citizens, and allowing for linkages to scientific processes (Baumert et al., 1999, pp. 5–6). Topics from physics, chemistry, biology, earth and space science, and technology complying with such criteria are represented in PISA by knowledge of science categories (classified according to physical systems, living systems, earth and space systems and technology) and knowledge about science categories (classified according to scientific inquiry and scientific explanations). They include:

> "Physical systems
> - structure of matter (e.g. particle model, bonds)
> - properties of matter (e.g. changes of state, thermal and electrical conductivity)
> - chemical changes of matter (e.g. reactions, energy transfer, acids/bases)
> - motions and forces (e.g. velocity, friction)
> - energy and its transformation (e.g. conservation, dissipation, chemical reactions)
> - interactions of energy and matter (e.g. light and radio waves, sound and seismic waves)
>
> Living systems
> - cells (e.g. structures and function, DNA, plant and animal)
> - humans (e.g. health, nutrition, subsystems [i.e. digestion, respiration, circulation, excretion, and their relationship], disease, reproduction)
> - populations (e.g. species, evolution, biodiversity, genetic variation)
> - ecosystems (e.g. food chains, matter and energy flow)

- biosphere (e.g. ecosystem services, sustainability)

Earth and space systems

- structures of the Earth systems (e.g. lithosphere, atmosphere, hydrosphere)
- energy in the Earth systems (e.g. sources, global climate)
- change in Earth systems (e.g. plate tectonics, geochemical cycles, constructive/destructive forces)
- earth's history (e.g. fossils, origin and evolution)
- earth in space (e.g. gravity, solar systems)

Technology systems

- role of science-based technology (e.g. solve problems, help humans meet needs and wants, design and conduct investigations)
- relation between science and technology (e.g. technologies contributing to scientific advancement)
- concepts (e.g. optimization, trade-offs, cost, risk, benefit)
- important principles (e.g. criteria, constraints, innovation, invention, problem solving)

Scientific inquiry

- origin (e.g. curiosity, scientific questions)
- purpose (e.g. to produce evidence that helps answer scientific questions, current ideas/models/theories guide enquiries)
- experiments (e.g. different questions suggest different scientific investigations, design)
- data type (e.g. quantitative [measurements], qualitative [observations])
- measurement (e.g. inherent uncertainty, replicability, variation, accuracy/precision in equipment and procedures)
- characteristics of results (e.g. empirical, tentative, testable, falsifiable, self-correcting)

Scientific explanations

- types (e.g. hypothesis, theory, model, law)
- formation (e.g. data representation, role of extant knowledge and new evidence, creativity and imagination, logic)
- rules (e.g. must be logically consistent; based on evidence, historical and current knowledge)
- outcomes (e.g. produce new knowledge, new methods, new technologies; lead to new questions and investigations)" (OECD, 2006, pp. 32–33).

However, scientific concepts are formulated on many different levels, ranging from comprehensive descriptions of science up to long lists of generalizations, as they are often presented in descriptions of curricular requirements (Baumert et al., 1999, p. 5).

2.2.2.3 Competences and Attitudes

A third realm of curricular dimensions includes all levels of competences and attitudes, representing cognitive, affective and operational components (Spada, 1980, p. 113). Frequently, the term "scientific habits of mind" is used for describing processes associated with the application of scientific, mathematical and technological knowledge to everyday life in terms of competences and attitudes, as they relate directly to a person's outlook on knowledge and learning and their ways of thinking and acting (AAAS, 1993, p. 322).

On a general level, the competence is understood as "the comprehensive precondition for problem-solving in a specific field of reality" (Schaefer, 2010b, p. 16). From a curricular perspective, Klieme et al. (2007, p. 21) point out that competences reflect basic demands on students in a certain domain. Referring to abilities in the context of general education, Klafki (2007, p. 63) defines basic competences of an educated person in the sense of *Allgemeinbildung* as argumentation skills, criticism and self-criticism, empathy, and complex thinking.

In light of the different and sometimes vague use of the term competence[11] and related terms such as meta-competence or key competencies both in everyday language and in research literature, substantial conceptual clarification is provided by Weinert (2001b). As competence covers – from innate personality traits to an acquired extensive body of knowledge, and from cross-curricular key qualifications to subject-specific skills – a wide range of denotations (cf. Weinert, 2001a), Weinert recommends a pragmatic approach in which competences should be conceptualized as the necessary prerequisites for meeting complex demands. More specifically, he describes competence as available or learnable cognitive skills and abilities of an individual to solve problems, and associated motivational, volitional and social skills and abilities required to successfully and responsibly apply problem solving in a variety of situations (Weinert, 2001b, pp. 27–28). Thus, competences cannot be reduced to their cognitive components, but include as integral parts ethical, social, emotional, motivational, attitudinal and behavioral facets, which together allow for effective action in specific situations (Rychen, 2008, p. 16). In this way, a competence can be seen

11 Due to the problem of clear distinctions, related terms such as competences, skills, abilities, and qualifications are used in this work interchangeably.

as a disposition that enables people to successfully solve certain types of problems, that is, to cope with situations of specific requirements. According to Weinert, the individual shapes of competence are determined by different interrelated facets such as ability, knowledge, understanding, action, experience, and motivation (2001b, pp. 27–8). The internal structure of a competence is defined by the demands, tasks, activities, interrelated attitudes, values, knowledge and skills that make effective action possible (Rychen & Salganik, 2002, p. 5).

The OECD DeSeCo[12] project provides an interdisciplinary approach to theoretically grounded conceptual foundations for identifying competences needed for individuals to lead responsible and successful lives in a modern democratic society and for society to face the challenges of the present and the future (cf. OECD, 2001, p. 3; Salganik, Rychen, Moser, & Konstant, 1999, p. 6). In line with Weinert's definition, the DeSeCo defines competences for applications such as in PISA (2001b, pp. 27–28) in a functional, external and demand-oriented approach, describing a competence as "the ability to meet individual or social demands successfully or to carry out an activity or task" that is "developed through action and interaction in formal and informal educational contexts" (OECD, 2002, pp. 8–9). Moreover, DeSeCo underlines the personal and social requirements individuals face and emphasizes that a competence is acquired and developed throughout life (OECD, 2005, p. 17).

In the context of school education, competences are primarily subject-based. This means that both subject-specific and more general, interdisciplinary competences can only be developed on the basis of and within the framework of certain subjects. However, the different subjects also have to be aware of their significance and have to fulfil their responsibility with respect to the development of central and universal competences. In this sense, the MNU argues that science education should promote both subject-specific and subject-transcending competences (MNU, 2003, p. 4). Describing scientific literacy as being composed of a domain-specific set of competences, Gräber et al. (2002, p. 137) distinguish between three dimensions of competences: knowledge (language and epistemological competence), acting (learning, communication, social, and procedural competence) and assessment (ethical and aesthetic competence). PISA 2000 (OECD, 1999, p. 62) applies a view of scientific literacy that enables it to be defined in terms of a number of scientific competences closely connected to conceptual content:

12 Definition and Selection of Competencies

- recognizing scientifically investigable questions
- identifying evidence need in a scientific investigation
- drawing or evaluating conclusions
- communicating valid conclusions
- demonstrating understanding of scientific concepts

In PISA 2006, these competences are modified and extended with a more process oriented focus (OECD, 2007b, p. 37):

- identifying scientific issues (recognizing issues that are possible to investigate scientifically, identifying keywords to search for scientific information, and recognizing the key features of a scientific investigation)
- explaining phenomena scientifically (applying knowledge of science in a given situation, describing or interpreting phenomena scientifically and predicting changes, as well as identifying appropriate descriptions, explanations, and predictions)
- using scientific evidence (interpreting scientific evidence and making and communicating conclusions, identifying the assumptions, evidence and reasoning behind conclusions, and reflecting on the societal implications of science and technological developments).

In a similar way, prerequisites for developing scientific literacy are described in terms of skills required for scientific and technological inquiry, solving problems, communicating scientific ideas and results, working collaboratively, and making informed decisions (Council of Ministers of Education, Canada, 1997).

Prominent core competences in these lists are thinking, communicating, problem solving, and inquiry. The statements of values and purposes accompanying these lists refer to connectedness, resilience, achievement, creativity, integrity, responsibility, and equity. It is, however, criticized that

> "for science educators and science teachers, this language of the knowledge society and what it means for education is almost entirely foreign" and "[e]ven problem solving is not elaborated in discipline-specific terms, but in generic strategies of various types" (Fensham, 2007, p. 116).

Fensham continues to point out that although PISA science has made a great contribution by defining competences that can be developed in science education, it is, as part of evaluative research that describes and measures wanted outcomes, not a curriculum. Nonetheless, PISA science can provide essential starting points for curriculum design (2007, p. 117).

In Germany, the national science education standards also describe the contribution of science education to students‘ scientific literacy through certain competences that students should achieve (KMK, 2005a, 2005b, 2005c). For each of the three common science subjects (biology, chemistry, physics), it distinguishes four areas of key competences: content knowledge, inquiry, communication, and evaluation. The domain content knowledge is represented by subject-specific basic concepts. Within this domain, it describes which phenomena, facts, terminology, applications, and laws the students should know and be able to relate to each other with respect to the different concepts. The domain scientific inquiry refers to methods and experimental techniques within scientific observation and the application of models which students should be able to carry out. The domain communication addresses aspects of task-oriented and issue-related accessing and sharing of information. The domain evaluation refers to recognizing and evaluating scientific issues in different contexts.

Following Weinert (2001b, pp. 27–28), competences include ethical, social, emotional, motivational, and behavioral components. Consequently, attitudes are closely associated to competences. In the tripartite view shared by Rosenberg and Hovland (1960), attitudes consist of cognitive, affective, and behavioral components. In this way, they constitute the affective basis of education (Schaefer, 2010b, p. 16). Attitudes play a significant role in students’ scientific literacy because they

> “represent a complex system of cognitions, feelings, and inclinations towards action, and [...] influence students’ continuing interest in and dispositions for positive and constructive responses towards science and science-related issues” (Bybee & McCrae, 2011, p. 23),

both in general and with respect to issues that affect them in particular. Sjøberg and Schreiner (2010, p. 4) underline that affective dimensions of science education are also relevant from the perspective of life-long learning and society. These considerations provide the rationale for including attitudes as a major part of curricular dimensions of science education.

As part of science competences and one of the four interrelated components forming the assessment of scientific literacy, a person’s disposition towards science in terms of attitudes as beliefs, motivational orientations, self-efficacy, and values is classified in PISA (OECD, 2007b, p. 39) as an individual’s

- support for scientific enquiry (acknowledging the importance of considering different scientific perspectives and arguments, supporting the use of factual information and rational explanations, expressing the need for logical and careful processes in drawing conclusions)

- self-belief as science learners (handling scientific tasks effectively, overcoming difficulties to solve scientific problems, demonstrating strong scientific abilities)
- interest in science (indicating curiosity in science and science-related issues and endeavors, demonstrating willingness to acquire additional scientific knowledge and skills, using a variety of resources and methods, demonstrating willingness to seek information and have an ongoing interest in science, including consideration of science-related careers)
- responsibility towards natural resources and environments (showing a sense of personal responsibility for maintaining a sustainable environment, demonstrating awareness of the environmental consequences of individual actions, demonstrating willingness to take action to maintain natural resources).

With respect to the citizenship dimension of scientific literacy, the *Canadian Framework of Science Learning Outcomes* in particular emphasizes that students should be encouraged to develop attitudes supporting the responsible acquisition and application of scientific knowledge to the mutual benefit of self, society, and the environment (Council of Ministers of Education, Canada, 1997).

In Germany, the MNU (2003, p. 10) classifies attitudes relevant in the context of (science) education as required by ability to participate in scientific and social life within three domains:

- learning and thinking
  - emotional: joy, curiosity, interest, perseverance, sensitivity, self-criticism
  - cognitive: various forms of thought such as analytic, synthetic, systemic, typological, causal, convergent, divergent, exclusive, inclusive etc.
- attitudes to oneself and to the environment:
  - communication, cooperation, tolerance
  - responsibilities to oneself and others
  - protection and care for one's own health and that of others as well as the preservation of the environment
- attitudes towards science and technology:
  - use, opportunities, sustainability
  - risks, safety
  - responsibility

With respect to the affective basis of science education, Bybee (2008, p. 570) moreover emphasizes that one important goal of science education is the development of students' attitudes supporting "their attending to scientific issues and the subsequent acquisition and application of scientific and technological knowledge to personal, social, and global benefit".

2.2.3 Summary

The issue that lies at heart of curricular research relates to the question how educational situations that are legitimated within the perspective of their social context and the individual development of the learners can be developed, realized and evaluated. Hence, the central aim of curriculum research is to find and apply methods through which contexts, contents, and abilities necessary for coping with different life situations can be determined. Frey points out the significance of curriculum development and criteria for the process of curriculum construction and development. Three areas can be distinguished as relevant curricular domains with respect to science education. The first domain refers to contexts in which processes of science education can be embedded and situations in which scientific knowledge and abilities are relevant. Scientific or science related topics and concepts represent the second domain. The third domain includes competences and attitudes with respect to scientific literacy, consisting of both cognitive and non-cognitive dimensions.

As society and particularly education systems and education policy are required to increasingly promote skills that enable people to deal responsibly and competently with different challenges, the question what skills are considered essential for future democratic societies is of growing importance (Rychen, 2008, p. 15). The OECD states that defining and selecting valuable, useful and legitimate competences is ultimately the result of a process in which researchers are partners among other stakeholders such as policy makers, practitioners, and representatives of the economic and social world (OECD, 2001, p. 4).

2.3 Curricular Processes in Science Education

Several elements of curriculum processes need to be considered with respect to curricular processes in science education. In order to take a closer look at determining factors for curricular processes in the context of science education, I will in the following sections illustrate elements that classify a curriculum process and the corresponding stages. Moreover, I will define central stakeholders in a science-related curriculum processes. In addition, I will introduce and describe the Delphi technique as a suitable instrument of a curricular process related to science education.

2.3.1 Components of a Curriculum Process

Tyler (1971) distinguishes three curriculum determinants with respect to considering curriculum content as relevant for educational purposes. These include individual relevance, social relevance, and scientific relevance. However, these determinants are characterized by a high degree of generalization, which is not sufficient to serve as the only legitimizing criteria (J. Mayer, 1992, p. 17). According to Frey (1980b, pp. 24–27), a curriculum process is constituted by three components, referring to focus and objectives, interaction and discourse, and reflection. Relating these components to curricular processes in science education, Frey (1980b, p. 24) points out that, first, principles related to general education as established in society need to be considered. These include, for example, the development of the individual and society as a major focus of education. Also, education should contribute to taking on responsibility in greater social contexts, guided by overarching ideals such as solidarity and equality. These objectives also apply to science education, through which – as part of general education – the realization of general and overarching educational goals can be pursued (cf. 1.2). Yet, a curricular process is not about an indoctrination of such objectives. Instead, through appropriate measures, it should be made possible that such objectives are considered and discussed within a curricular process (Frey, 1980b, p. 25). Following Häußler and his colleagues (1980), in the curricular approach of this study this notion is accounted for through the overall method, that is, through an open initial question, the selection of participants, and the iterative way of processing the questions throughout several rounds (cf. 6.3).

With regard to the second component, interaction and discourse, it can be argued that the experiences and insights of experts in a certain domain represent a valuable knowledge basis from which important information for a given issue can be obtained (Häder, 2009, pp. 92–94). Hence, with respect to the basic curricular question regarding what aspects of science education are appropriate for both the learners' personal development, it is important that as well other persons than those being professionally involved with science are included in a curricular process towards desirable science education. It is thus necessary to involve different stakeholders with a range of expertise and backgrounds (see 2.3.2) who relate to the aforementioned objectives of science education (Frey, 1980b, p. 25). Additionally, the interaction of such different stakeholders is an important aspect as it is also essential that curricular discussions of desirable science education develop and provide the opportunity to be addressed in a discursive way (cf. Frey, 1980b, p. 26).

Furthermore, a curricular process requires specific reflection, the third component. In the course of such processes, the element of reflection features a constructive effect in dealing with the interaction within the frame of the objectives. This demand avoids that desirable aims and contents of science education are determined through consultation of the total population, as democracy alone cannot guarantee a legitimate educational concept, no more than a reproduction of discipline-specific expertise can (cf. Frey, 1980b, p. 26). In this way, the systematic involvement of selected groups of participants should be enhanced by diverse interaction and reflection. Relevant stakeholders for a curricular process concerning the question of desirable science education are discussed in the following.

2.3.2 Central Stakeholders of Curriculum Processes in Science Education

Emphasizing scientific literacy as the overarching goal of science education rather than discipline-based purposes poses the question of whose voice should be heard with respect to the science curriculum during the compulsory years of schooling (Symington & Tytler, 2004, p. 1404). Generally, there are several groups with a stake in science education. Such stakeholders, being directly or indirectly affected by science education, often have multiple demands as they deal with issues of science education from different perspectives (Roberts, 1988, p. 28). Hence, science education is a field with different stakeholders having both an interest in and an influence on the curricular matters of science education (AAAS, 1993, 2001; e.g. Aikenhead, 2003; Häußler et al., 1980; Sjøberg & Schreiner, 2010).

According to Aikenhead (2003, pp. 15ff.), groups that decide or should decide what is relevant regarding educational perspectives in science curricula include academic scientists and education officials ("wish-they-knew science"), people facing real-life decisions related to science and curriculum policy researchers ("need-to-know science"), people with careers in science-based industries and professions ("functional science"), mass media and internet ("enticed-to-know science"), experts interacting with the general public on real-life matters pertaining to science, such as public health experts, environmental experts, and economics ("have-cause-to-know science"), students at school ("personal curiosity science"), and people engaged in the field of culture (science-as-culture").

With respect to the field of science communication, Burns et al. (2003, p. 184) distinguish in a similar way six relevant, partly overlapping groups in society. These include "scientists" (industry, academic community and government), "mediators" (science communicators, journalists and other members of the media, educators, and opinion-makers), "decision-makers" (policy makers and scientific and learning institutions), the "general public" (the three groups above, and other interest groups such as students in school), the "attentive public" (the part of the general community already interested in – and reasonably well-informed about – science and scientific activities), and the ”interested public” (composed of people who are interested in but not necessarily well-informed about science and technology). Some researchers have criticized the failure to involve relevant members of society in curricular processes in science, as

> “from the literature it is apparent that little is known concerning the views of the community generally about the purposes that science education should set out to achieve” (Symington & Tytler, 2004, p. 1404).

Given the multiple purposes of science education as identified with respect to scientific literacy (cf. 2.1.3), it can be argued that in a debate about desirable aspects of science education, it would be appropriate to seek the opinions of further members of society affected by science, capturing in this way “a community voice that would represent responsible and informed views” (Symington & Tytler, 2004, p. 1405). This claim to extend the scope of stakeholders given a voice in science curricular discussion has received widespread support by a number of scholars and shows a growing awareness of the important role of different members of society in developing appropriate science curricula for scientific literacy (Symington & Tytler, 2004, p. 1404).

However, with defining the public as every person in society, it has to be acknowledged that *the public* with its needs, socio-economic settings and cultural conditions is a very heterogeneous group. Also, it has to be recognized that not every person in society is affected by or involved in science education. Hence, the question arises which members of the public are directly or indirectly affected by and involved in science education and can thus be considered as relevant stakeholders. Representing a within-school view, students and teachers with science subjects surely should have a significant say about what happens in schools in relation to science learning (Symington & Tytler, 2004, p. 1404). In this way, it is argued that a comprehensive and integrated recognition of the voices of students and teachers is necessary to make informed, research-based decisions on designing school science curricula and teaching (Christidou, 2011, p. 141). This view is supported by taking into account the process of education as “an open, complex and recursive system of an intersubjective nature, within which relations and communication between members of the classroom community (i.e. teacher and students) create new, common worlds and contribute to the co-construction of meaning and the constitution of students’ identities” (Christidou, 2011, p. 142). Thus, students and science teachers can be identified as two important stakeholder groups with respect to science education. However, while acknowledging the importance of the views of students and teachers, it needs to be recognized that these two groups cannot alone be expected to represent a broader community perspective in the context of science education (Symington & Tytler, 2004, p. 1404). Therefore, additional members of the public affected by and involved in issues of science education and the school science curriculum, such as scientists, the science education research community, and education policy, have to be consulted (Roberts, 1988, p. 27). The following sections describe these groups and the rationale for considering them as relevant stakeholders for science education in more detail.

2.3.2.1 Students

Students are obviously important stakeholders in the field of science education (e.g. Beattie, 2012; Fielding, 2001, 2004; Jenkins, 2005, 2006; Klafki, 2007; Meyer & Reinartz, 1998; Roberts, 1988; Ruddock et al., 2003; Rudduck & Fielding, 2006), as

> "there is something fundamentally amiss about building an entire [education] system without consulting at any point those it is ostensibly designed to serve" (Cook-Sather, 2002, p. 3 quoted in Jenkins, 2006, p. 1).

However, in most societies, aspects that are both important and salient within a given domain, such as science education, are usually defined by the academic community (Osborne et al., 2003, p. 693), which suggests that the voices of students represent "a crucial element still too often overlooked" (Nixon, Martin, McKeon, & Ranson, 1996, p. 270 quoted in Jenkins, 2006, p. 1) or even entirely absent from science curriculum related debates (Osborne & Collins, 2001, p. 442). Yet, with respect to young people's contributions to today's and tomorrow's world, there is a growing recognition that students are capable of insightful and constructive analysis of their experiences of learning in school and are able to make contributions to the development of strategies for improving learning and raising achievement (Ruddock et al., 2003). Thus, scholars increasingly notice that students have a right to be heard and have something worthwhile to say about their school experiences including their science education (Ruddock, 2003, p. 1).

On the basis of these considerations and with students as the main and final users in each educational system, it seems reasonable to argue that curricular matters of science education must also be approached from the perspective of the learner and should satisfy the needs of these learners rather than only the science education community or adult society.

The assumptions about the important role of student voice can also be linked to the German theory of *Bildungsgangdidaktik* (Meyer & Reinartz, 1998; Schenk, 2005), which especially takes into consideration the individual and his or her process of *Bildung*. With the focus on the individual in light of the theory of *Bildungsgangdidaktik*, Meyer (2005, p. 18) defines *Bildung* as a social process in the course of which the individual develops. In the context of formal education, this understanding of *Bildung* emphasizes the students' perspectives in the process of education and also underlines the importance of exchange and communication between adolescents and adults within this process. From a German *Bildungs*-oriented perspective, Klafki (1995b, p. 194) also emphasizes the necessity to mediate between the current interests and experiences of the learners, their current problems within their everyday lives on the one hand and the perspectives beyond this context with respect to the young peoples' future tasks and opportunities, both as individuals and as part of a larger society on the other hand. However, Klafki stresses that student-orientation alone is as misplaced as the establishment of instruction solely from the perspective of an educating generation claiming to be able to anticipate what the next generation will need in the sense of attitudes, insights, abilities and skills to cope with their future. On the basis of these arguments, it becomes apparent that both students and "adult" stakeholder groups represent relevant voices in science education.

2.3.2.2 Teachers

One of the central findings of research in teacher education and expertise is that teachers are central predictors for the realization of effective and modern education and that they play an essential role in implementing innovations (EC, 2007; Hattie, 2009, 2012). In science education, teachers are key figures in the formation and reorganization of students' conceptions and attitudes towards science, as teachers' views and beliefs determine to a large extent their teaching practices (Christidou, 2011, p. 146). The development of research and teaching material as well as policy recommendations are further areas of teachers' involvement and driving force. Sjøberg and Schreiner (2010, p. 2), as well as Roberts (1988, p. 27), point out that this particularly applies to those teachers who are organized and involved in teacher networks and science teacher associations or other networks such as science societies and science centers, which can have a further impact, especially through projects, journals, conferences, or formulating and promoting position statements. In light of these notions, the importance of teachers as stakeholders and decision makers in science education and the central role they play in the development of scientifically literate citizens is widely acknowledged (AAAS, 1997; Millar, 1996; Roberts, 1988; Schreiner & Sjøberg, 2004).

2.3.2.3 Science Education Researchers

Further stakeholders in science education are represented by researchers in the academic field of science education as a professionalized field with academic degrees and positions, research centers, professional associations at regional, national, and international levels, a high number of international professional conferences, and also several national as well as international academic journals (Sjøberg & Schreiner, 2010, p.2).

Science education researchers – who may also be science teachers and/or working in teacher training – can be considered to be evidence providers of factors that affect science education through their research studies, as they can be expected to hold informed views in their area of research. Also, science education researchers play a significant role in handling the education of pre-service teachers at university. Recognizing that their science education students are likely to be teaching for more than 30 years into the future, science education researchers can be said to have the most forward looking perspectives among the different stakeholder groups in science education (PROFILES, 2010a, p. 20). Closely related to the field of science education research are authors and contributors of science textbooks and curriculum actions, as they are involved in producing materials for student and teacher use (Roberts, 1988, p. 27).

2.3.2.4 Scientists

An additionally relevant stakeholder group in the field of science education are scientists (PROFILES, 2010a, p. 21; Sjøberg & Schreiner, 2010, p. 2). This group includes research scientists such as university scholars and staff members (Roberts, 1988, p. 27), as they influence the teaching of science and textbooks in terms of so-called fundamental ideas (PROFILES, 2010a, p. 21). Moreover, the group of scientists refers to professionals in science-related industry and workplaces, who might as managers, decision makers or employers hold particular interest in the enhancement of scientific literacy (PROFILES, 2010a, p. 21; Sjøberg & Schreiner, 2010, p. 2). In this way, this group is often referred to as the "science community" or as "science practitioners" (Burns et al., 2003, p. 184). The professional bodies of scientists are organized in numerous associations on regional, national, or international levels. They provide several policy documents and position statements related to school science education, as their associations and academies often contain sub-groups dealing with school science and science in the public (Sjøberg & Schreiner, 2010, p. 3). Of all stakeholders, scientists working within the science field in the public sector or in industry have the most practical viewpoint from a "life skills" perspective, as they deal with science-related attributes that are important in the workplace (PROFILES, 2010a, p. 21). However, as these stakeholders do not have a direct impact on those who usually act as decision makers in curricular matters of science education, their voice is often ignored (PROFILES, 2010a, p. 21).

2.3.2.5 Education Policy and Administration

Policy makers and curriculum developers are an additionally important stakeholder group, as they determine both guidelines and boundaries for the teachers through the intentions of the curriculum, external examination goals, regulations, or the setting of standards for science teaching in schools. Thus, their views have great impact on the practice of science education (PROFILES, 2010a, p. 21). Stakeholders for science education in the group of education policy includes persons in Ministries of Education with a direct remit towards science teaching, science curriculum developers, curriculum committees in school systems appointed by government departments, further formal national educational authorities and education administration, or others such as local town councils with an interest in the enhancement of scientific literacy (PROFILES, 2010a, p. 21; Roberts, 1988, p. 27).

2.3.3 The Delphi Technique as an Instrument for the Investigation of Curricular Aspects of Science Education

A process involving the investigation of curriculum content in terms of desirable science education as targeted in this study represents a complex issue. With respect to the central elements of a curriculum process (cf. 3.1), this issue can be explored by obtaining opinions of experts from different areas in a systematic way, as following Frey (1980a, p. 30) such a process requires on the one hand involving a number of stakeholders through an appropriate way and on the other hand accounting for the requirements of systematic reflection and participation in the different stages of this process. A suitable method for such a complex endeavor emerges through the Delphi technique, which is considered an appropriate approach to gain access to the knowledge of different experts in a given domain (Häder, 2009; Häder & Häder, 2000). Studies suggest that in terms of accuracy, the Delphi method as one of various group-decision making processes outperforms unstructured group judgment as well as standard interacting groups (Bolger, Stranieri, Wright, & Yearwood, 2011; Rowe & Wright, 2001) and is thus frequently applied to a range of judgment problems (Ayton, Ferrell, & Stewart, 1999). Having already proven its applicability in the field of education and curriculum-related research (Bolte, 2003a, 2003b, 2008; Edgren, 2006;

Farmer, 1995; Häußler et al., 1980; Heimlich, Carlson, & Storksdieck, 2011; Judd, 1972; Marshall, Currey, Aitken, & Elliott, 2007; J. Mayer, 1992; Osborne et al., 2003; Reeves & Jauch, 1978; Rice, 2009; Robertson, Line, Jones, & Thomas, 2000; Rockwell, Furgason, & Marx, 2000; So & Bonk, 2010; van Zolingen & Klaassen, 2003; Welzel et al., 1998; Wicklein, 1993; Yang, 2000), the Delphi method is considered a suitable tool for collecting and structuring experts' opinions on educational issues (Ammon, 2009, p. 462; Häder, 2009, p. 238; Häder & Häder, 2000, p. 14; Linstone & Turoff, 1975a, p. 10).

2.3.3.1 The Delphi Method

The Delphi technique is a special form of written consultation and represents a highly structured method of group communication. More specifically, it is a widely acknowledged way of accessing, collecting, organizing and condensing views and opinions of a panel of experts on a given topic throughout several consecutive rounds in a systematic way (Aichholzer, 2002; Ammon, 2009; Ayton et al., 1999; Becker, 1974; B.B. Brown, Cochran, & Dalkey, 1969; Bernice B. Brown, 1968; Dalkey, 1969; Häder, 2009; Häder & Häder, 2000; Kenis, 1995; Linstone & Turoff, 1975c; Murry & Hammons, 1995; Seeger, 1979). Considering the variety of Delphi applications, the Delphi method is defined in a number of different ways, according to the particular context and depending on which aspect is emphasized (Ammon, 2009, p. 459). Linstone and Turoff (1975a, p. 9) have defined the Delphi technique as

> "a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem".

This elicitation of expert opinion is a central feature of the Delphi method and allows for an aggregation of available knowledge, experience and judgment of experts (Häder, 2009, p. 21). Overall, the results of Delphi studies thus serve to gain insights about aspects that are difficult to determine and that can in this way provide guidance and support for the accomplishment of tasks and the realization of goals. For these reasons, the Delphi method is in particular applied in view of complex decisions in order to gain access to the expertise of persons with different perspectives on a given issue (Ammon, 2009, p. 461).

The name of the Delphi method derives from the antique oracle of Delphi in Greece, which provided predictions through which political and social influence was exercised during the 5th and 6th century A.D. (Häder, 2009, p. 13). The first use of an approach with reference to the Delphi oracle in modern times relates to the context of forecasting results of dog or horse races in 1948 (Häder, 2009, p.

15). In the United States, the Delphi method was developed as a tool for group communication concerning the access of expert opinion for technological forecasting by the Air Force-sponsored RAND Corporation[13] in the context of defense research (Dalkey & Helmer, 1963, p. 458; Linstone & Turoff, 1975a, p. 16). The aim of this first Delphi study was to

> "obtain the most reliable consensus of opinion of a group of experts [...] by a series of intensive questionnaires interspersed with controlled opinion feedback" (Linstone & Turoff, 1975a, p. 16).

The initial rationale for the Delphi method is based on Dalkey's assumption referred to as the 1+n argument, which suggests that 1+n persons can provide at least as much information as one person, but most likely, 1+n minds would be able to offer more information (Häder, 2009, p. 38). The first published Delphi study appeared in 1964 in the *Report on a Long Range Forecasting Study* by the RAND Corporation (Häder, 2009, p. 15). In the following years, the Delphi method was adapted in a variety of areas and became a widely used technique both in the public and in the private sector. Much of the subsequent use of the Delphi method refers to the purpose of predicting technological developments. Additional common areas of application include several other fields with judgment issues such as industrial planning, telecommunications, education, tourism, economic development, medical progress and health policy, regional development, environmental research, and government (Häder & Häder, 2000, pp. 13–15; Linstone & Turoff, 1975a, p. 10).

With various modifications and the great diversification of methodical features especially since the 1970s (Häder & Häder, 2000, p. 15), several types and sub-types of Delphi emerged (Häder, 2009, p. 19). Häder (2009, pp. 29–35) distinguishes between four different types of Delphi studies with respect to its general objectives. The first refers to the generation and aggregation of ideas as the main focus, representing an all-qualitative approach. The second type relates to the goal of achieving predictions that are as accurate as possible of an unclear issue or uncertain situation. The third type applies to Delphi studies that primarily aim to empirically identify and display a group of experts' views on a diffuse issue. The results of such studies serve, for example, to gain specific conclusions for carrying out interventions to react to an issue identified in this way. The fourth type gives particular emphasis to inducing group communication processes through the feedback component that lead to establishing consensus among the participating experts. The type applied within this study refers to the third

13 The RAND (Research and Development) Corporation is a think tank in the United States providing expertise on economic, social and defense issues (The RAND Corporation, 2013).

type, as the purpose of this study mainly focuses on empirically identifying and displaying a group of experts' views on a complex issue. However, while there are many varieties of Delphi, common to all are design considerations including aspects such as the initial question, expertise criteria, sample size, questionnaire design, iteration, number of rounds, anonymity of the participants, feedback, structure of information flow, panel mortality, and mode of interaction (see 2.3.3.1.).

In general, a Delphi study undergoes four distinct phases. The first phase is characterized by an exploration of the subject with the aim of determining the objectives of the study and reaching an operationalization of the overarching question. The second phase refers to the process of establishing a questionnaire for collecting expert opinions in order to gain an understanding of how they view the issue. The third phase involves an evaluation of the previous results by the central monitoring team of the study and feedback of the results to the experts. This phase includes possibly repeating the collection of the experts' views, looking at their potential change of view on the basis of the feedback of the previous results until a predefined ending criterion is reached. The last phase takes place when all previously gathered information has been analyzed and the evaluations have been fed back for consideration, and concludes with a final evaluation (Häder, 2009, p. 25; Linstone & Turoff, 1975a, pp. 5–6). The general procedure of a Delphi study is addressed in more detail in 3.3.1.10.

The "classical" Delphi approach can be characterized by several key features (Häder, 2009, p. 25; Häder & Häder, 2000, p. 17):

- a formalized question format as a means for the collective opinion-making process taking place within the study
- involvement of individuals that can be considered experts within the field of investigation
- a fixed group of participants who are consulted with respect to a certain issue
- anonymity of the participants
- statistical aggregation of the group's responses, which allows for a quantitative analysis and interpretation of data
- feedback of the results to the participating experts to inform them about the other experts' opinions, providing them with the opportunity for reflection – and, if applicable, reconsideration, clarification or change – of their views in light of the answers from the aggregate expert group
- iteration, which allows the experts to modify their views in light of the aggregate group's response through the feedback (see above) from round to round, which also allows for a gradual condensation of the general question

- a central monitoring group, which administers through a radial communication structure the data collection, the analyses, and the reciprocal information flow of the feedback

Through these features, it becomes apparent that the Delphi method includes elements of both quantitative and qualitative research, although it is listed among quantitative methods of data collection (Bortz & Döring, 2006, p. 261).

Häder (2009, p. 41) points out that cognitive aspects play a central role with respect to the underlying rationale of the Delphi method. Normative social influence and processes of group dynamics are regarded as a major influence on group judgment and decision making (Deutsch & Gerard, 1955; Woudenberg, 1991). In particular, in situations with unclear or complex issues, people may look to others as a source of information, which Deutsch and Gerard (1955) refer to as informational social influence. In this way,

> "[t]he Delphi technique was largely developed to avoid the problems of freely interacting groups, such as dominant individuals and pressure to conform to the majority view" (Bolger & Wright, 2011, p. 1500).

As outlined more precisely in 2.3.3.1.6, these sources of "process loss" are avoided by anonymization and controlled feedback (Bolger & Wright, 2011, p. 1500).

With respect to the cognitive background of participants' judgment formation in the first round of a Delphi study, Häder and Häder (2000, p. 24) refer to the information processing paradigm of personality (cf. Asendorpf, 2007), through which every individual can be described as an information processing system and which states that incomplete information can generally be supplemented by the knowledge of other individuals. Such processes occurs through active internal construction, for example in the form of a feedback process between perception, memory and information search. This notion leads to the assumption that iteration improves the quality of a Delphi study.

Bardecki indicates that "[t]he processes involved in an individual's response to the Delphi method are conditioned by a number of psychological effects" (1984, p. 281). As a major aspect, Bardecki identifies factors related to continuing participation in subsequent Delphi rounds (see 2.3.3.1.8).

In the following sub-chapters, central aspects with regard to the design of Delphi studies are outlined in more detail.

2.3.3.1.1 Initial Question and Question Types

A crucial aspect at the outset of a Delphi study is the operationalization of the issue. The facet theory of the social sciences provides a systematic approach to the preparation of the initial question of the study (cf. Borg, 1992). This theory is used to split a more general question or abstract issue into relevant dimensions (Häder, 2009, p. 88).

As it is generally assumed that with broad, open-ended questions, a wider range of responses can be gained than from a narrow set of questions, the context of the issue in a given Delphi study is usually structured into a qualitative first round and several, subsequent quantitative rounds (Häder, 2009, p. 87). The questions in the qualitative first round should be formulated on a more general level in order to provide the participants with a wide frame for their considerations. In this way, it can be avoided that the participants feel too restricted by guidelines (Häder, 2009, p. 116).

Throughout the study, the questions of the first qualitative round of a Delphi study develop into more focused and specific questions. With an iterative process like this (see 3.3.1.5), the experts' central opinions can be obtained and ideas in the course of subsequent rounds will be increasingly concretized and summarized (Häder, 2009, p. 116).

The decision for a particular question type is closely connected to the concept and purpose of the study. In general, there is a wide range of different question types that can be applied in a Delphi study. Question types which can be distinguished in the context of Delphi studies relate, for example, to choosing between different given possibilities, setting priorities, estimating consequences, pointing out alternatives, defining desirable und undesirable developments, exploring impacts, polling new needs etc. (Häder, 2009, p. 125). Engaging and concise formulations can entice potential experts' willingness to participate (Burkard & Schecker, 2014, p. 160; Skulmoski, Hartman, & Krahn, 2007, p. 10).

2.3.3.1.2 Expertise Criteria and Structure of the Sample

The deliberate selection and composition of the group of participants is of central importance with respect to the quality of the study, as the outcomes of a Delphi study are based on the participants' responses (Ammon, 2009, p. 464; Häder, 2009, p. 92). In this regard, Bolger and Wright (2011, p. 1507) point out that the process of a Delphi study is only successful if it involves a sufficient level of expertise in the panel. Hence, Delphi participants should meet certain expertise requirements. With the composition of the group of experts depending closely on the purpose of the study (Ammon, 2009, p. 464), Häder and Häder (2000, p. 18) point out that it is important to include experts with broad knowledge and comprehensive experience in the topic of the study so that a wide range of views and perspectives is represented. A determining factor for choosing experts is thus their affiliation with a context relevant for the issue of the given study (Ammon, 2009, p. 464).

Another important aspect is to ensure heterogeneity in the expert panel (Bolger & Wright, 2011, p. 1510; Linstone & Turoff, 1975a, p. 10). Hence, Delphi panelists should be chosen to represent different viewpoints (Ammon, 2009, p. 464), as in this way, “the likelihood that multiple frames on a situation will be generated within individual panelists is increased” (Bolger & Wright, 2011, p. 15101). Furthermore, the chosen Delphi participants should have the willingness, the capacity, the personal interest, and the endurance to participate throughout the different rounds of the study. An additional aspect is to focus on experts who are potentially able to disseminate and apply the results into practice within their context of influence (Häder, 2000, p. 18). Including experts with known “maverick” opinions could, moreover, enhance the process as they prompt and promote challenges to conventional thinking (Bolger & Wright, 2011, p. 1510). In general, it can be said that the selection of participants in a Delphi study is the determining and thus critical factor for the quality of its outcomes (Ammon, 2009, p. 466).

2.3.3.1.3 Sample Size

The question of sample size is closely connected to the context and specific purpose of a given Delphi study (Ammon, 2009, p. 465). Therefore, experiences with a large scale of different sample sizes in Delphi studies are reported (Häder & Häder, 2000, p. 18). As there are no general rules for an optimal size of a Delphi sample, the literature provides a variety of recommendations for the number of participants in a Delphi study (Häder, 2009, p. 96). Many recommendations range between 10 and 50 panelists (Häder, 2009, p. 96; Nworie, 2011, p. 26; Okoli & Pawlowski, 2004, p. 19). However, others point out that under appropriate conditions, even smaller groups of panelists can successfully participate in a Delphi study. Parenté and Anderson-Parenté (1987, p. 149) mention a number of ten participants as the minimum size of a Delphi panel. As a minimum size for sub-groups in differentiated analyses, researchers have suggested a critical threshold of seven participants (Becker, 1974, p. 12; Dalkey, Brown, & Cochran, 1969, p. 6). This number can also be linked to a theory known as *Miller's Law* from the field of information processing psychology, which suggests that the number of seven is a crucial element in a variety of applications in the context of dealing with complex systems and which implies that discussions with seven participants are most efficient (Miller, 1956). Nworie points out that smaller sample sizes are often recommended from a logistical perspective based on practical matters related to the coordination of Delphi study activities (2011, p. 26).

Many researchers assume that larger expert panels might help to reduce inaccuracy (Häder & Häder, 2000, p. 18). Accordingly, Ammon (2009, p. 465) points out that the more complex the topic of a given Delphi study is, the larger the size of the sample should be. Therefore, for Delphi studies with the aim of quantifying and qualifying opinions of experts, scholars recommend to involve as many participants as possible (Häder, 2009, p. 110). However, in the case of an all-qualitative Delphi study with the aim of determining opinions and arguments, fewer participants might be sufficient (Häder, 2009, p. 101).

A determining factor for the initial size of a Delphi sample is the estimated panel mortality (see 2.3.3.1.8). As the response rate usually diminishes throughout the different rounds, the initial sample should be large enough to provide a sufficient number of participants in the respective sub-groups in the last round after drop-out, thus promising sufficient data quality for interpretation (Ammon, 2009, p. 465).

2.3.3.1.4 Design of Questionnaires

With respect to designing questionnaires in Delphi studies, the specific characteristics of the Delphi method need to be considered (Häder, 2009, p. 122). In each round, a Delphi questionnaire should include information about the results of the corresponding previous round. As the survey takes place throughout several rounds, the questionnaires are labeled with identification numbers to allow for panel data analysis and response rate control. The participants of Delphi studies are not to be understood as test persons, but take on the role of informants. Thus, for the design of the questionnaires, it should be kept in mind that it is not the task of the participants to produce situation-based reactions. Rather, they are supposed to provide well-considered responses regardless of the survey situation. As opinion polling in a Delphi study generally takes place in written format, there is no need for taking into consideration elements of interviewer influence. In the quantitative rounds of Delphi studies, the questionnaires contain mostly standardized questions.

Usually, Delphi questionnaires are sent via mail or electronically. For paper-and-pencil based Delphi studies, a cover letter, a data protection statement, the questionnaire, a prepaid return envelope, and, if needed, additional information should be included. To obtain a high response rate, a number of recommendations with respect to design issues of questionnaires in Delphi studies can be retrieved from literature (Häder, 2009, p. 121). For the cover letter, an official letter head should be used. The purpose of the cover letter is to inform the experts thoroughly about the content and aims of the study. In particular, the purpose of the study and the importance of the experts' participation should be highlighted. Furthermore, the experts should be addressed personally and confidentiality should be assured. An appreciation of their efforts should be expressed as well. Also, it has been found that the length of the questionnaire has a negative effect on the response rate when exceeding approximately 12 pages. Furthermore, the questions and the structure of the questionnaire should be plausible. To facilitate the processing of the questionnaire, the questions should be arranged in a clear way and the sequence of the questions should be arranged in a top-down order. Questions related to the same issue should be grouped together into blocks of questions (Häder, 2009, pp. 122–124).

2.3.3.1.5 Iteration and Number of Rounds

As iterating the response process is a way of improving accuracy within a given group discussion (Häder, 2009, p. 207; Linstone & Turoff, 1975b, p. 234), Delphi studies are usually conducted as repeated interrogations throughout several rounds (Häder & Häder, 2000, p. 15). Bolger and Wright (2011, p. 1511) underline that it is especially "[t]he iterative feedback [that] sets Delphi apart from other nominal group techniques", as in this way, the Delphi method replaces direct confrontation and discussion by a systematic course of sequential individual interrogations through questionnaires, putting an emphasis on informed judgment (Bernice B. Brown, 1968, p. 7).

The number of rounds in a Delphi study is variable and depends on the purpose of the study as well as some pragmatic aspects. In general, it is argued that the validity of the results of the study is increased throughout the rounds (Linstone & Turoff, 1975b, p. 234). However, as the effort required of Delphi participants increases with the number of rounds, the response rate often diminishes over the rounds (see 3.3.1.8). Usually, the iterative process of polling and feedback is conducted until a predefined ending criterion is reached (Häder & Häder, 2000, p. 17). This can be, for example, the number of rounds, solidity of the results, consensus achievement, theoretical saturation, or when sufficient information has been exchanged (Häder & Häder, 2000, p. 119; Rowe & Wright, 1999, p. 355).

Reports of several applications of the Delphi method state that satisfying results were reached after three rounds (Häder & Häder, 2000, p. 17), as three rounds

> "[m]ost commonly […] proved sufficient to attain stability in the responses; further rounds tended to show very little change and excessive repetition was unacceptable to participants" (Linstone & Turoff, 1975b, p. 229).

For this reason, Delphi studies are typically conducted within three rounds (Häder, 2000, p. 17), with most of the changes taking place between the first and second round (Woudenberg, 1991, p. 140).

2.3.3.1.6 Anonymity of the Participants

The anonymity of the experts is an essential aspect with respect to the legitimization of the Delphi method. It is assumed that on the basis of anonymity, it is more convenient for the participating experts to revise their opinions without reservations, as an anonymous survey situation prevents them from a lost loss of prestige (Häder, 2009, p.148). Also, anonymity allows the experts to freely express their own opinions. It avoids influence through processes of group dynamics which can occur in common group processes as a source of inaccuracy and which can be induced by factors such as domination by quantity, group pressure towards conformity (Häder & Häder, 2000, p. 22), or the presence of opinion leaders (known as "bandwagon effect"), (Linstone & Turoff, 1975a, p. 4). Moreover, it can be assumed that an anonymous survey situation increases the experts' willingness to participate, as estimation and decision-making in complex issues can be related to some tentativeness or unease (cf. Kenis, 1995). Some researchers interpret anonymity among the participants in a Delphi study as a disadvantage, as participants in anonymous situations cannot be held responsible for their views and might in this way deliver blindfold or unelaborate statements. However, this assumption could not be empirically proven (Häder, 2009, p. 148).

2.3.3.1.7 Feedback and Structure of Information Flow

A further crucial aspect of the design of a Delphi study is the feedback of the results to the participating experts after each round. The feedback is directed by a central monitoring group and serves to inform the participants about the other experts' opinions. This provides them with the opportunity for a reflection – and, if applicable, reconsideration, clarification or change – of their views in light of the answers from the whole expert group. The feedback can be given in a variety of possible forms, including mean values, measures of dispersion, tables, graphs, statements etc. In case of verbal statements from the participants, common feedback strategies in the context of the Delphi method include an appropriate preparation and integration of such information into numeric feedback by the central monitoring group. In case of numeric assessments by the participants, statistical figures should be provided. The most common measure for the central tendency in the participants' assessments is represented by the arithmetic mean. Measures of dispersion are of particular importance in this case, as arithmetic mean values do not provide information about the variety and the distribution of the assessments. In such context, dispersion measures serve as indicators of the heterogeneity of the participants' views. A suitable measure for the distribution of responses emerges through the standard deviation (Häder, 2009, p. 151). In addition to the direct feedback, the researchers should provide the experts with access to detailed accounts of the results after each round and they should have the opportunity to ask the monitoring team for additional information (Häder, 2009, p. 156).

2.3.3.1.8 Panel Mortality

The retention of participants in a Delphi study is a crucial factor for the success of the study, as their commitment to the study throughout the different rounds is directly related to its success. Only if the knowledge of the participating experts can be continuously accessed from the first to the last round and is integrated into the feedback accordingly, optimal quality of the results can be expected (Häder, 2000 p. 19). Early withdrawal of experts can lead to information loss (Häder, 2009, p. 157).

The degree of experts' commitment to participating in a multi-round Delphi study is represented by the round-by-round response rate. The anticipated response rate is an important factor with respect to determining the size of the initial sample. However, the response rate in Delphi studies is difficult to estimate. In the first round of a Delphi study, usually about 30% of the contacted participants take part; in the following rounds, a response rate of about 70-75% can be expected. Previous experiences with the Delphi method show that high dropout rates occur especially between the first and second round of a Delphi study. As the elaboration on the tasks within a Delphi study usually requires much effort from the participants (Häder, 2009, p. 157), the response rate in Delphi studies also depends on the issue of the given Delphi study, the degree of its complexity, and the scope of the questions and tasks (Häder, 2009, p. 112).
Häder (2009, p. 158) lists three assumptions why experts abandon the Delphi process. The first refers to situations in which a participant's assessment deviates strongly from the other experts' opinions. In this case, elements of cognitive dissonance (cf. Festinger, 1962) might represent a motive for terminating participation (dissonance hypothesis). The second assumption relates to participants with more extreme assessments than the other experts. In this case, the large difference between the participant's own opinion and the other experts' views might cause the participant to leave the interrogation (non-conformity hypothesis). The third reason for participants' dropout from a Delphi process is connected to situations in which a participant provides his or her assessment with high

uncertainty. The discontinuation of subsequent participation might in this case appear due a perception of their own incompetency (competence hypothesis). However, these hypotheses are not commonly agreed on and could not be confirmed empirically in several analyses. Therefore, dropout of Delphi participants could also be ascribed to other, more pragmatic factors such as a lack of time (Häder, 2009, p. 159).

A specific problem appears if, for example, systematic dropout of a certain sub-sample occurs. In this case, the views of a certain group would be underrepresented or lost. Hence, particular attention should be paid to non-response cases. This issue stresses the importance of sending additional reminders to the participants. Experiences indicate that after such reminders, approximately the same response rate occurs as in the corresponding original round (Häder, 2009, p. 159). For a reduction of dropout rates, sending reminders in time intervals of one, five, and seven weeks, and extending the deadlines, if possible, has proven successful (Häder, 2009, p. 123). In order to ensure that the targeted sample composition is reached, continuous response rate control by the monitoring team is recommended (Häder, 2009, p. 113).

2.3.3.1.9 Mode of Interaction

In Delphi studies, different modes of interaction are possible. In general, the communication throughout a Delphi study takes place in written form. This makes it possible to involve experts from different places. Initially, Delphi studies were conducted as paper-and-pencil versions with questionnaires being sent and returned by mail. In the 1970s, the application of real-time Delphi studies was tested in the USA, but due to the limited technological options during that time, it was only possible to involve a low number of experts. However, the advancement of communication technology provides new possibilities for the application of the Delphi method, for example, through electronic mail or web-based questionnaires. A great benefit of electronic communication in a Delphi study is that addressing the participants and the data collection can be directed in more efficient ways. However, the choice of interaction modes largely depends on the target group (Ammon, 2009, p. 464).

2.3.3.1.10 General Procedure

In the conventional Delphi process, the monitoring team designs a questionnaire which is sent to the anticipated respondent group (Linstone & Turoff, 1997a, p. 11). In general, the issue of the study is approached in a first qualitative round, which is followed by subsequent quantitative rounds (Häder, 2009, p. 87). The goal of the qualitative first round is the acquisition of a differentiated series of basic statements, representing a wide range of different views and thus avoiding one-sidedness of the study (Häder, 2009, pp. 116ff.). After the questionnaire is returned, the monitoring team analyses and summarizes the results, in the course of which the content of the responses is standardized in terms of language and is fed back to the participants. Based on these results, the monitoring team develops a questionnaire for the following round. In this way, the statements of the first qualitative round are subject to standardized assessment in the course of subsequent rounds. The participants are usually given at least one opportunity to reevaluate and refine their opinions in terms of ranking or rating their original answers based upon examination of the group response (Häder, 2009, p. 116; Linstone & Turoff, 1975a, p. 11).

2.3.3.2 Curricular Application of the Delphi Method

The Delphi technique can be effectively modified to meet the needs of a given study (Häder, 2009; Linstone & Turoff, 1975c). In investigations on educational issues, the Delphi method proves to be particularly suitable, as previously conducted curricular Delphi studies show (see 2.4). In curriculum related research, curricular Delphi studies in particular serve to gain insights in the context of determining educational goals, curriculum content and competence standards (Burkard & Schecker, 2014, p. 159; Häder, 2009, p. 238).

Following Frey (1980a, p. 32), the classical Delphi method as outlined above can be specified for curricular adaption by three additional elements. The first element relates to framing the overarching question with additional advice at the beginning of the interrogation and specifying aspects to induce reflection and at the same time to avoid stereotypical answers. The second element refers to collecting views and opinions within a curricular structure that is specified by different curricular dimensions such as contexts and situations, topics and concepts, and competences and attitudes (cf. 2.2.2). This element systematizes the interrogation, ensures that the statements of the participating experts relate to potential curricular situations and thus avoids a collection of only broad and common objectives, terminology, and domains. In this way, the general question is specified within a formal question and answer format. The third aspect refers to criteria for selecting experts involved with curricular matters, as being part of society does not inevitably qualify for being considered as an expert in the field of curriculum research. Thus, selecting participants on the basis of these criteria ensures a group of experts that is legitimated from a curricular perspective.

In the curricular modification of the Delphi method, the focus is on normative and subject-specific considerations of education (J. Mayer, 1992, p. 97).

With this purpose, a curricular Delphi study inquires of a wide range of opinions. As divergence can occur in interrogations that contain issues of value conflicts such as in the field of education, it is possible that instead of convergence, dissent appears within this range of views. However, as Mayer (1992, p. 97) points out, dissent regarding educational concepts does not rule out a consensual acceptance of the validity of such different opinions, as the discourse does not aim at a consensus of values but at consensual reflection on the legitimacy of different values.

2.3.4 Summary

A curriculum process is constituted by three elements. These refer to focus and objectives, interaction and discourse, and reflection. Following Frey (1980b, pp. 27–28), the curricular process carried out within this study for answering the question of desirable science education in terms of scientific literacy is based on the following assumptions:

- The question of desirable aspects of science education cannot be answered by one expert alone, but different experts are necessary who feature certain characteristics. Generally, the experts should comply with the overarching objectives of education in general and science education in particular. Moreover, the groups of experts should be competent with respect to the question of desirable science education.
- The curricular process of inquiring, collecting answers, providing feedback etc. is to be designed in such a way that it supports enlightening and systematic reflection.
- The experts engaged in this curricular process should interact with each other through systematic reflection.
- The outcomes of the curricular process should provide the possibility for further elaboration and adaption to other persons involved with curricular matters of science education as well.

Therefore, a crucial factor in a curriculum process is the involvement of appropriate stakeholders. As relevant stakeholders in the context of desirable aspects of science education, students with different science subjects, science teachers (including science education students at university, trainee science teachers, in-service science teachers, and science teacher supervisors), science education researchers, scientists, and representatives from education policy and administration can be identified. These stakeholder groups represent experts to be included in a reflection on the curricular content of desirable scientific literacy based science education.

An appropriate way of collecting and structuring experts' opinions on educational issues is represented by the Delphi method, which has already proven suitable to compile views on complex issues such as contexts, contents and aims of education. The Delphi method is a specific form of structured group communication and is used for accessing the expertise of numerous persons with different competent perspectives on a given issue. A particular advantage of the Delphi method for the purpose of this study is the anonymity of the participants. As outlined in chapter 2.3.3.1.6, ensuring respondents' anonymity avoids several negative effects such as influence by opinion leaders that can emerge from direct group interaction and face-to-face discussion. Another significant aspect is the iterative and controlled feedback, which promises greater accuracy and thus more solid results. Furthermore, the open initial situation question is an important factor, as it helps to avoid narrow initial responses. Through the written form of communication, a high number of experts from different places can be involved. This is of particular importance both with regard to the international framework which this study is part of and with respect to subsequent meta-analyses. The curricular adaption of the Delhi method includes three additional elements. First, the overarching question at the beginning of the study is supplemented with additional advice and specifying aspects to initiate reflection and avoid stereotypical answers. Secondly, views and opinions are collected within a curricular structure specified by different curricular dimensions such as contexts and situations, topics and concepts, and competences and attitudes. This is done in order to systematize the interrogation, obtain statements relating to potential curricular situations and avoiding broad and common objectives, terminology, and domains. The third element refers to criteria for selecting experts dealing with curricular issues and in this way being legitimated from a curricular perspective.

2.4 Science Education in Light of Subject Specific Curricular Delphi Studies

Various studies have been conducted with the aim of gathering and exploring views of various groups of stakeholders on specific issues of science education. The Delphi method has frequently been used to investigate and clarify curricular aspects regarding several sub-domains or subject-specific issues of science education (Bolte, 2003a, 2003b, 2008; Edgren, 2006; Häußler et al., 1980; Heimlich et al., 2011; J. Mayer, 1992; Osborne et al., 2003; Welzel et al., 1998). In the following, I will describe three examples of subject-specific curricular Delphi studies in the context of science education in Germany. The studies explore the views of several stakeholders from different domains associated with school science and focus on desirable aspects of biology, physics, and chemistry education respectively as part of general education.

2.4.1 Physics

The first curricular Delphi study in science dates back to the 1980s and was conducted by Häußler and his colleagues (1992; 1980). The study focused on "physics education of today and tomorrow". The authors of the study used the curricular Delphi method (see 2.3.3.2) to determine aspects of desirable physics education, drawing on the expertise of an initial sample of 73 stakeholders selected according to specified criteria. The stakeholders represent different groups associated with physics and physics education, e.g. physics teachers, physics education researchers, physicists, employees in physics-related industry or other related contexts, education policy, members of curriculum committees, and general educationalists (Frey, 1980c, pp. 38–41). Within three consecutive rounds, these stakeholders were asked for their opinions on the question "what should physics education look like so it is suitable for someone living in our society as it is today and as it will be tomorrow?" (Häussler & Hoffmann, 2000, p. 691). The first round gathered the participants' initial views on this issue in an open questionnaire format that was divided into the curricular domains of contexts and situations, topics and concepts, and qualifications. In the second round, the degree of priority and realization in the classroom of the collected aspects was determined. Also, the participants developed more particular statements regarding desirable physics on the basis of the given aspects through assembling combinations from the given categories. Moreover, the relevance of physics education was assessed in relation to other fields of education in a third task. Through a hierarchical cluster analysis, the category combinations of the participants were merged into concepts of desirable physics education. These concepts were subject of the third round and were again assessed by the participants. Here, the assessment focus was on the concepts' importance and the degree of their realization in practice as well as further aspects of the initial research question. Moreover, the participants were asked to outline content-based specifications of a given group of themes for educational situations on the basis of the concepts (Häußler et al., 1980).

The results of the qualitative round of this study yielded 54 aspects that were assigned to an either scientific, professional, cultural, social, or personal domain. Contextual categories of desirable physics education included, for example, the scientific structure of physics, insights into the professional world, basic qualification for careers, understanding of the implications of scientific and technical developments and the risks associated with it, avoiding safety hazards and accidents in daily life, household and living environment, leisure, society and public, consumer behavior, emotional personality area, gratification in dealing with science, intellectual personality area, and general education (Häußler & Rost, 1980a; Hoffmann & Rost, 1980)

With respect to desirable content of physics education, topics related to "scientific knowledge and methods as mental tools", "passing on scientific knowledge to the next generation", "physics as a vehicle to promote practical competence", and "physics as a socio-economic enterprise" were given highest priority (Häußler & Hoffmann, 2000, p. 693). This shows that the participants saw physics "more as a human enterprise and less as a body of knowledge and procedures" (Häußler & Hoffmann, 2000, p. 704). In general, the outcomes of the priority assessments suggest some degree of consensus among the participants concerning the different aspects of cultural and social relevance of physics education, the knowledge domains, and competences. As for the significance of physics education for the individual, about half of the participants emphasized the cognitive and emotional relevance. The other half stressed aspects relating to practical issues of everyday life. The practice assessments showed that in most of the cases, the practice assessments fell short of the priority assessments. Particularly high deficiencies, indicated through the priority-practice differences, were attributed to competency aspects such as problem solving, socio-political acting, self-reflection, and applying knowledge (Rost & Spada, 1980, pp. 188–191).

The five concepts obtained from cluster analysis of the category combinations relate to "responsible socio-political acting and public discussion of physics and technology" (1), "mastering and understanding physical and technical devices" (2), "enhancement of the emotional experience of nature and technology and satisfying occupation with physics" (3), "promotion of an occupation with the scientific tradition of physics as an intellectual endeavor" (4), and "insights into the professional domain and qualification for professional life" (5) (Häußler & Rost, 1980b, p. 220). According to the priority and practice assessments of the concepts, the largest perceived deficiencies appeared for the concept related to responsible socio-political acting and public discussion of physics and technology (1). This finding can be understood as a clear vote by all participating experts for a stronger orientation of physics education towards the requirements of responsible participation of the individual in society and public debate (Rost & Spada, 1980, p. 254).

As the sample of the curricular Delphi study in physics does not include students as stakeholders for physics education, views of about 500 students on the issues investigated in this study were addressed in a follow-up study, investigating their interests in the contents, contexts, and activities that were suggested by the curricular frame of this Delphi study (cf. Hoffmann & Lehrke, 1986). In this follow-up study, a “remarkable congruency between students' interest in physics and the kind of physics education identified in the Delphi study as being relevant” could be identified. In addition, „a considerable discrepancy between students' interest and the kind of physics instruction practiced in the physics classroom” was determined (Häußler & Hoffmann, 2000, p. 689). Moreover, the results of the follow-up study showed that similar to the priority-practice differences determined in the curricular Delphi study on physics, mismatches for the concepts from the curricular Delphi study on physics appeared between the interests of the students and the degree of their perceived realization in the classroom. In this way, the results suggest that an orientation of physics education towards the particular concepts may be crucial in terms of students’ interests (Häußler, 1992, p. 139).

2.4.2 Biology

Following the work of Häußler et al. (1980), Mayer (1992) conducted a Delphi study on the issue of biodiversity in the context of compulsory biology education. Tying in with the notion that the task of didactic discourse is to make choices about educational contents that should be considered relevant with respect to general education, the study focused on the overarching curricular question of which contents of biodiversity are relevant and pedagogically desirable for the individual in the society of today and the near future. The responses to this question were compiled in a curricular frame that involved educational goals, methods, and relevant content related to biodiversity such as biotopes, biocenoses, and living beings (Mayer, 1992, p. 12).

In this study, the views of an initial sample of 77 participants were collected in three rounds. The sample consisted of different stakeholders that qualified as experts with respect to the question of the study. These included biology teachers, biology education researchers, educators, biologists in research, industry, and administration, students at the level of upper secondary education, and representatives from out-of-school educational contexts. Starting with an open three-part questionnaire, the overarching question is in the first round were specified into contexts (I), content (II) and competences (III), as done in the Delphi study in physics by Häußler and his colleagues (1980). In the second round, a synopsis of the first round took place through the participants’ combinations of categories derived from the responses in the first round. These were merged into meaningful statement complexes, and category frequencies were determined. The category combinations were further specified by the participants with respect to particular organisms and biotopes. Concepts of teaching topics related to biodiversity were derived through hierarchical cluster analysis of the category combinations as well as from the content specification provided by the participants, In the third round, these concepts were assessed by the participants according to their priority, and further opportunities for extending the lists of relevant species as well as selecting the most important ones are provided (p. 99).

With respect to contexts and motives of teaching content related to biodiversity, 15 different categories were determined. The most frequently mentioned aspects with respect to the issue of the study included the protection of endangered species and dealing with environmental problems, an enlightened appreciation of nature, an understanding of the scientific tradition of biology, an emotional relation to nature, and coping with life. The question about desirable content related to biodiversity yielded 17 thematic areas, referring to systematic, morphological, ecological, recreational, and application based aspects. Special emphasis was placed on ecological considerations and students' everyday life. With regard to the question of competences to be enhanced through biodiversity related content, 15 aspects of knowledge, skills, methods, and attitudes were determined. In their assessment, the participants placed great emphasis on the knowledge of names and manifestations of animals and plants, the classification and systematization of species, a critical attitude towards human treatment of nature, and protective and responsible behavior regarding living beings. The cluster analysis yielded five concepts with regard to addressing biodiversity in the classroom. These include "living beings within the context of ecology and environment protection" (1), "living beings as part of general biological and physiological manifestations" (2), "dealing with living beings from the perspective of diversity of organisms and their systematization" (3), "occupation with living beings in the context of leisure and experiencing nature" (4), and "living beings in light of advantages and harms for humankind" (5). In general, the results show that teaching about biodiversity can take place within numerous topics of biology education. Moreover, Mayer argues that addressing biodiversity should also be considered as an overall task of biology education. In conclusion, he points out that dealing with biodiversity in the biology classroom should not take place in an isolated way from other content, but in combination with general and applied biology and along descriptive and analytical methods (pp. 272–275).

2.4.3 Chemistry

Following the approaches by Häußler and his colleagues (1980) and Mayer (1992), Bolte (2000, 2001, 2002, 2003a, 2003b, 2008) used the Delphi method to determine aspects of meaningful and pedagogically desirable chemistry education considered relevant for the scientifically literate individual in the society of the present and the future. For this purpose, the study analyzed dimensions as well as fields of dissent and consensus in the opinion of 114 stakeholders. The particular aim of the Curricular Delphi Study in Chemistry was to facilitate

> “a reflection on content, task, and aims, as well as the development of guidelines for a modern scientific literacy based – chemistry-related – basic science education from different stakeholders’ views” (Bolte, 2008, p. 334).

Collecting the views of students, chemistry education students at university, trainee and in-service chemistry teachers, trainee teacher supervisors, chemistry education and science education researchers, representatives of chemistry teacher associations, chemists, and other professionals from science-related fields, the study covered different groups that are affected by chemistry-related science education (Bolte, 2003b, p. 12).

In the first round, these experts provided their opinions on aspects of desirable chemistry education in an open questionnaire, which was structured according to contexts, situations, and motives (I), content (II), and qualifications (III). Their statements were analyzed by means of qualitative and quantitative methods and were summarized into categories. These categories were reported back to the participants for weighted assessment in the following round. In light of the general opinion of the expert panel, the participants assessed the priority and the extent to which these aspects were realized in practice. This process revealed which characteristics featured higher and which featured lower importance in the participants’ opinions. On the basis of these assessments, priority-practice differences were calculated to identify especially deficient areas in chemistry education and the degree of consensus among the stakeholder groups about assessing these aspects was determined. In addition, with the aim to identify concepts of desirable chemistry education, the participants were asked to compile meaningful category combinations. Identified through cluster analytical processes, these concepts were fed back to the participants for weighted evaluation analogously to the second round and for further assessment in the third round (Bolte, 2003b, pp. 9–10, 2008, pp. 335–336).

In the results of the first round, general trends as well as specific emphases can be identified in the opinion of the participants. The analysis of the participants’ statements yields a total of 60 categories of desirable chemistry education. As expected by the author of the study, the identified aspects coincided to a great extent with those criteria included in recommendations for modern chemistry education by didactic and teacher associations, but also enhanced those recommendations with further aspects (Bolte, 2003b, p. 13). Moreover, the results of the first round revealed a shift of focus in the context of desirable and modern chemistry education, pointing to the importance of embedding chemistry based topics in everyday life related contexts, interdisciplinary or multi-perspective approaches to topics, and the consideration of qualifications that provide the basis for lifelong learning in chemistry. This shifted focus was also supported by the quantitative analyses (Bolte, 2003b, p. 14). They revealed that all participants placed high emphasis on aspects related to household, everyday life, the environment, basic knowledge, nutrition, health, sustainability, relation of chemistry to social issues, historical perspectives, scientific chemistry-related developments, understanding, judgment abilities, and action competence (Bolte, 2003b, pp. 15–17).

With respect to the category frequencies of the four sub-samples of this study (students, teachers, education researchers and scientists), the differentiated analyses support the author's initial consensus-dissent-hypothesis, which assumed a gap between the expectations of science education and the educational interests of large sections of the population (Bolte, 2008 p. 333). More specifically, the results show that on the one hand, there seems to be a general consensus among the participants on several content related aspects of science education, but on the other hand, the four different sub-samples show different accentuations in their views on meaningful and pedagogically desirable aspects of chemistry related scientific literacy of the individual in the society of today and tomorrow (Bolte, 2003b, p. 20). Hence, the results suggest that

> "the much praised consensus about the importance of scientific education and about how this education should be realized, is seemingly inappropriate" (Bolte, 2008, p. 341).

In particular, Bolte found that the group of young people and the three adult subsamples expressed different ideas. This finding supports what Bolte calls the "hypothesis of the educational conflict of the generations". This hypothesis relates to the notion that science curricula are mostly developed by experts who are scientifically socialized, as well as the fact that the content of science lessons is for the most part determined by the teachers – whereas students do not necessarily share the opinions and priorities of these groups. With respect to educational intentions and educational offers, chemistry education is thus "dominated by adults' conceptions of good general education, whereas young people's educational interests remain ignored" (Bolte, 2008, p. 333). In the Curricular Delphi Study in Chemistry, this discrepancy is particularly shown by contrasting the students' views with those of the scientists. As these differences are primarily the result of certain aspects being hardly mentioned by the group of students in the first round, Bolte moreover raises the question whether this might be related to the fact that the these characteristics appear only barely or implicitly in common chemistry education, which leads to the "versatility-versus-one-sidedness-hypothesis" (Bolte, 2008, p. 341). He argues that

> "if science lessons are primarily planned and held according to the structure that the pure subject lays out (science first), and problems in society or in the world are only dealt with afterwards […], then it is obvious that there is an imbalance between the central intentions of chemistry related to formal education (personal relevance first) and chemistry related specialization undertaken in schools" (Bolte, 2008, p. 333).

On the basis of the iterative process of the Delphi method, more solid claims about this assumption were retrieved from the results of the second round.

The results of the second round of the Curricular Delphi Study in Chemistry show that out of the given 60 categories from the first round, only three aspects were assessed as not so important (priority mean ≤ 2.75), all other 57 categories were assessed as important or very important. This indicates the validity of the classification system. From the practice perspective, however, only eight of these aspects were assessed as being present in chemistry lessons. These categories refer to aspects that relate to chemistry as a science and structure-of-the-discipline approaches (Bolte, 2008, p. 341). Categories representing everyday life or nature of science-oriented aspects were, on the other hand, assessed as sparsely present in chemistry lessons. Furthermore, as almost all categories featured large priority-practice differences, the results show that according to the participating experts, chemistry education needs improvement (Bolte, 2008, p. 342). Areas identified by the experts as most deficient and thus featuring the most urgent need for change include aspects referring to motivation and interest, value systems, judgment ability, reflected action, and multi-disciplinary approaches (Bolte, 2008, p. 344). The results of the second round also show that the three hypotheses can statistically not be falsified. Moreover, the quantification of the second round revealed several aspects that could generate and enhance discussions about chemistry as an essential part of general education (Bolte, 2008, p. 343).

All in all, the outcomes indicate that chemistry related science education needs reform. In particular, chemistry education in practice is still found to be characterized by an overemphasis on aspects related to chemistry as a science, and less oriented towards issues of general education, as demanded in frequent discourse on scientific literacy. As a result, chemistry teachers have to take into account that the perception of current conventional chemistry lessons does – as assessed by the experts in the Curricular Delphi Study in Chemistry – not coincide with desirable chemistry education. This applies both to the adult stakeholder groups and the group of students. Furthermore, Bolte has pointed out that "to enhance scientific literacy, it is necessary to have both sides in mind and to focus on both, the educational expectations of society (or of the 'adults') and the educational interests of the younger generation", negotiating aims and topics of chemistry related science education with both students and adults as representatives of society. The findings of the Curricular Delphi Study in Chemistry can help to bridge the gap between these groups (Bolte, 2008, p. 344). Considering scientific literacy as a major aim of science based general education, the results furthermore imply that in chemistry related curricular discourse, it is crucial to clarify the genuine contribution of chemistry to a modern worldview and to explain which scientific-cultural advancements the prosperity and quality of life in industrialized societies is based on. This should be embedded in an understanding that it can be personally fulfilling to be able to reflect on problems of one's own living environment from the perspective of chemistry (Bolte, 2003b, p. 24).

2.4.4 Summary

The notion of the need to include members of society in a discourse on curricular aspects of science education has generated several studies which address the views of different stakeholders. The curricular Delphi method has been established and applied as a particularly appropriate method for addressing curriculum related issues within a structured group discussion. The three curricular Delphi studies outlined above follow the same general design: A fixed group of participants is interrogated about aspects of desirable aspects of physics, biology, and chemistry related science education throughout three consecutive rounds. They are selected on the basis of specified criteria according to their science education related backgrounds and include students, teachers, education researchers, scientists, and representatives from education associations and education policy. For ensuring anonymity among the participating stakeholders, their views are collected and analyzed by a central working group, which administers the information flow. In a first round, their views are collected in an open questionnaire and classified into categories. In a second round, the results from the first round are fed back to the participants for further (quantitative assessment) allowing for reconsideration of their own opinions in light of the group opinion. In a third round, concepts of science education with respect to the subject-specific focus of the corresponding study derived through cluster analyses of category combinations from the second round are fed back to the participants again for weighted assessment. All three studies point out general tendencies as well as specific insights with regard to their particular foci of science education and reveal a need for action in science education within their field of investigation, providing specific starting points and orientation frameworks for improving physics, biology, and chemistry related general education.

2.5 Research Questions and Hypotheses

In the preceding chapters, essential aspects that are connected to processes of determining scientific literacy based science education were addressed. On the basis of the theoretical reflections, the need for a comprehensive approach towards desirable scientific literacy based science education from the perspective of different stakeholders in society was pointed out. For this reason, the main aim of the Curricular Delphi Study in Science is to investigate the views and opinions about desirable aspects of scientific literacy based general education of affected members of society such as students, teachers, science education researchers, and scientists. The central question of this study is:

What aspects of science education are by different stakeholders considered meaningful and pedagogically desirable for the scientifically literate individual in the society of today and tomorrow?

This question is specified within several research questions and investigated on the basis of the corresponding hypotheses. To find answers to this question, a suitable method for collecting and processing different stakeholders' views is needed. As shown by several scholars, the Delphi method has proven to be a suitable instrument to investigate stakeholders' opinions on curricular aspects in different science subjects (Bolte, 2003a, 2003b, 2008; Häußler et al., 1980; J. Mayer, 1992; Osborne et al., 2003).

Based on the works of Bolte (2003a, 2003b, 2008), Häußler (1980), and Mayer (1992), I expect that through the Delphi method, a valid classification system for desirable aspects of science education can be obtained. As in previous Delphi studies of science education and with reference to widely acknowledged aims and objectives of science education, I expect that several aspects expressed by the stakeholders of this study relate to recommendations in literature. Furthermore, based on sample and methodological similarities, I expect that the views provided by the stakeholders of this study relate to aspects collected in previous Delphi studies. However, in view of the integrative approach to science education in this study and the large time interval between this study and the aforementioned previous Delphi studies, I also expect that the statements provided by the stakeholders of this study include additional aspects. On the basis of these considerations, I address the following research question and hypotheses.

1. What expectations of desirable science education can be identified in the stakeholders' views?

Hypothesis 1a: Through the curricular Delphi method, a valid classification system for desirable aspects of science education can be reached.
Hypothesis 1b: The aspects of desirable science education expressed by the participants of this study relate to recommendations from literature and to aspects collected in previous curricular studies associated with science education, but also include additional aspects.

Following Bolte (2003a), I expect that the stakeholders assign highest priority to aspects related to scientific inquiry, environmental issues, content knowledge, and overarching aims of general education. As well, I expect on the basis of the results obtained by Bolte that, in contrast, the stakeholders give lowest priority to aspects connected to the structure of the science disciplines, specialized fields, and traditional approaches of single subject orientation. Taking into account the progression of complexity in science education towards higher levels of education (KMK, 2005a, 2005b, 2005c), I assume that the priority of all aspects increases with more advanced levels of education.

Based on the results by Bolte (2003a) with respect to the perceived presence of aspects desirable science education in the science classroom, I expect that aspects related to the structure of the science disciplines, specialized fields, and traditional approaches of single subject orientation are assessed with the highest extent of realization. Following Bolte (2003a) and based on frequently demonstrated failures of science education to meet overarching aims of education (e.g. Deutsches PISA-Konsortium, 2001; OECD, 2004a, 2007b, 2010), I anticipate that the stakeholders assign lowest degrees of realization to aspects related to interdisciplinarity, students' living environment, ethical references, and overarching aims of general education. Taking into account recommended progressions in science education such as expressed in the national education standards (KMK, 2005a, 2005b, 2005c), I expect that the extent of realization of all aspects increases with more advanced levels of education.

According to Bolte (2003a), a gap between science educational practice and the educational interests of large sections of the population can be identified. More specifically, for most aspects considerable discrepancies between stakeholders' priorities of desirable chemistry related science education and their actual perception of reality of appear in terms of an underrepresentation of these aspects in practice. Therefore, I expect that for most of the aspects of desirable education that are identified throughout this study, substantial priority-practice differences appear in terms of their perceived realization not living up the stakeholders' priorities. Following further results obtained by Bolte (2003a), I assume that most of the largest priority-practice differences appear for aspects considered as most important by the stakeholders. These expectations are specified on the basis of the following research questions and hypotheses, which allow for statistical evidence whether these expectations can be confirmed.

2. What emphases can be identified in the stakeholders' views?

Hypothesis 2a: Highest priority is given to aspects related to scientific inquiry, environmental issues, content knowledge, and overarching aims of general education.
Hypothesis 2b: Lowest priority is assigned to aspects connected to the structure of the science disciplines, specialized fields, and traditional approaches of single subject orientation.
Hypothesis 2c: The priority of aspects depends on the level of education and increases with more advanced levels of education.

3. To what extent are aspects of desirable science education realized in practice according to the stakeholders' views?

Hypothesis 3a: Aspects related to the structure of the science disciplines, specialized fields, and traditional approaches of single subject orientation are assessed with the highest extent of realization.
Hypothesis 3b: Aspects related to interdisciplinarity, students' living environment, ethical references, and overarching aims of general education are assessed with lowest extent of realization in current science education.
Hypothesis 3c: The extent of realization depends on the level of education and increases with more advanced levels of education.

4. What differences between priority and extent of realization regarding aspects of science education can be identified in the opinions of the stakeholders?

Hypothesis 4a: For the majority of the aspects, considerable priority-practice differences appear.
Hypothesis 4b: For most aspects, their realization falls short of their priority.
Hypothesis 4c: For the highly prioritized aspects, especially large priority- practice differences can be identified.

Differentiated analyses of the curricular Delphi study in chemistry (Bolte, 2008 p. 333) provide insights about whether the sub-samples share some consensus or drift apart in their opinions (consensus-dissent-hypothesis). On the one hand, there seems to be some general consensus among the participants on aspects of desirable chemistry related science education. However, on the other hand, the four sub-samples feature different emphases in their views (Bolte, 2003b, p. 20). This points to several distinctions in the stakeholders' opinions about meaningful and pedagogically desirable aspects of chemistry based scientific literacy of the individual in the society of today and tomorrow and suggests that the frequently claimed consensus about the how to realize scientific literacy based science education best with respect to chemistry education is not appropriate (Bolte, 2008, p. 341). Following these findings, I expect that those aspects considered most desirable for science education by the sub-samples in this study broadly correspond to each other, but however, the sub-samples differ in their specific assessments of aspects of desirable science education.

The Curricular Delphi study in Chemistry (Bolte, 2008, p. 333) furthermore reveals that particularly the group of young people and the three adult sub-samples express different ideas (hypothesis of the educational conflict of the generations). Bolte relates this finding to the notion that science curricula are mostly developed by experts who are scientifically socialized and that science lessons are mostly determined by teachers, whereas students do not necessarily share the opinions and priorities of these groups, so that chemistry education is mostly dominated by adults' conceptions of good science education, whereas young people's educational interests remain ignored. As today, science education is still seen as usually defined by the academic community (Nixon et al., 1996, pp. 270, quoted in Jenkins, 2006, p. 1; Osborne & Collins, 2001, p. 442; Osborne et al., 2003, p. 693), I expect that in the Curricular Delphi Study in Science, a gap between the assessments of the young generation and the adult groups regarding aspects of desirable science education appears.

These expectations are specified by the following research question and hypotheses.

5. Is there a consensus among the different stakeholder groups regarding their opinions assessments of aspects of desirable science education?

Hypothesis 5a: The aspects considered most desirable for science education by stakeholders of the different groups broadly correspond to each other.

Hypothesis 5b: However, the stakeholder groups differ in their specific assessments of aspects of desirable science education.

Hypothesis 5c: There is a particular gap between the assessments of the young generation and the adult groups regarding aspects of desirable science education.

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