Chapter 1
The Concept of Competence and Its Relevance for Science, Technology and Mathematics Education

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Locating the Concept of Competence in Relation to Other Concepts

During the last decades, the conditions under which people live have changed rapidly. Advances in science and technology have influenced the way people live, and environmental problems have destroyed many people's livelihood in many regions of the world. Globalisation means events happening in places far away affecting people's everyday lives worldwide. Thus, people are confronted with new opportunities but also with new challenges and problems. Therefore, living in today's complex world requires adaptation to new conditions as well as lifelong learning. Consequently, educational systems have to respond to these societal, economic and ecological changes by defining new educational goals that are reflected in the concept of competence. Competences are demand and function oriented. In order to solve complex problems, people should be able to realise certain competences in a particular context and to transfer these competences to other contexts. They thereby provide one foundation for lifelong learning. However, looking at the literature, the

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J. Dolin, R. Evans (eds.), *Transforming Assessment*, Contributions from Science Education Research 4, DOI 10.1007/978-3-319-63248-3_1

concept of competence is not unambiguously defined and some confusion exists with respect to related constructs like Bildung or literacy. The reason is that the construct of Bildung is understood as a more 'general formula for what is expected from (lifelong, not just school-based) learning processes [constituting] a precise description of the ability of subjects to act under the conditions of undecidability, indeterminacy, uncertainty and plurality' (Klieme et al. 2004, p. 59). In comparison, competences have a stronger focus on what students should be able to do in order to, for example, compete in the labour market of a modern society:

> When scholars of educational science speak about the general goals of training within modern societies, they quarrel with finding a balance between [on the one hand] Bildung in the tradition of German philosophy, i.e. developing personality and allowing individuals to participate in human culture, and [on the other hand] qualification, i.e. establishing knowledge and skills that are relevant for vocational practice. (Klieme et al. 2008, p. 6)

In addition, the concept of competence is also closely linked to the concept of literacy as it is operationalised in international large-scale studies like the Programme for International Student Assessment (PISA). The PISA framework for scientific literacy emphasises the importance of the application of scientific knowledge and skills in the context of real-life situations. This application of knowledge and skills is influenced by students' attitudes or dispositions towards science that can determine 'their level of interest, sustain their engagement, and may motivate them to take action' (OECD 2016, p. 20). In a similar way, the definition of mathematical literacy in PISA strongly emphasises the need to develop students' 'capacity to formulate, employ and interpret mathematics in a variety of contexts' (OECD 2016, p. 65) that reflect the 'range of situations in which individuals operate in the twenty-first century' (OECD 2016, p. 73).

Rychen and Salganik (2003) even argue that the 'convergence between the concept of literacy as defined in current assessment frameworks and DeSeCo's [the OECD project 'Definition and selection of competences'] concept of competence, and the difficulties associated with the definition of the term literacy, together suggest that international assessments would benefit from replacing the concept of literacy with the concept of competence' (p. 53).

The Concept of Competence in Education

In many countries, a shift from an input- towards an output-orientation could be observed within educational systems (Waddington et al. 2007). Instead of relying solely on extensive content descriptions, educational standards define competences as learning goals for students at specific stages of their educational career (e.g. National Research Council 2012; Qualifications and Curriculum Authority 2007; Schecker and Parchmann 2007). Despite this importance, however, the definition of the construct has to some extent remained fuzzy within educational research (e.g. Blömeke et al. 2015; Koeppen et al. 2008; Weinert 2001). In his review of theory-grounded approaches to the concept of competence, Weinert (2001) found that no broadly accepted definition or unifying theory existed. Instead, a tendency could be observed ‘to use terms such as skill, qualification, competence, and literacy, either imprecisely or interchangeably, in order to describe what individuals must learn, know, or be able to do in school, at the workplace, or in social situations (Rychen and Salganik 2003, p. 41).

In 1997, the Organisation for Economic Cooperation and Development (OECD) initiated the DeSeCo project with the aim of providing solid theoretical and conceptual foundations for the broad range of competences needed to face the challenges of the present and the future. They considered an explicit definition of the meaning and nature of competences crucial to enable a coherent discourse on competences from a lifelong learning perspective. In line with an earlier recommendation by Weinert (2001), the project decided on a demand- or function-oriented approach to define competences: ‘A competence is the ability to successfully meet complex demands in a particular context through the mobilization of psychosocial prerequisites (including both cognitive and non-cognitive aspects)’ (Rychen and Salganik 2003, p. 43). In order to avoid reducing competences to mere *ability-to* expressions, the demand-oriented approach requires the conceptualisation of competences as internal mental structures, i.e. resources embedded in the individual such as cognitive skills, intellectual abilities (e.g. critical thinking) and knowledge but also social and behavioural components such as motivation, emotion and values. Moreover, possessing a competence includes an action component. Individuals always operate in specific contexts that set the criteria for effective performance. It is thus not sufficient to possess the different resources but one must be able to mobilise and orchestrate them in a complex situation. This understanding of competence is consistent with the action competence model described by Weinert (2001) that represents a holistic and dynamic perspective by combining complex demands, psychosocial prerequisites and contexts into a complex system that people need in order to solve problems. It is necessary to convert this very general definition into more domain-specific definitions, e.g. what does it mean to be competent in science, technology or mathematics?

In educational contexts, the concept of competence usually refers to those context-specific dispositions for achievement that can be acquired through learning, in contrast to basic cognitive abilities that can only be learned and trained to a far lesser degree (Klieme et al. 2008). Understanding competences as reflecting a person’s potential to meet cognitive demands in specific areas of learning and behaviour makes them amenable to external interventions such as opportunities to learn and systematic training, thus increasing the utility of the concept for teaching and learning as well as for the empirical assessment of educational outcomes (e.g. Klieme et al. 2008).

Despite the huge amount of research in the last decade however, a recent review still considers competence to be a ‘messy construct’ (Blömeke et al. 2015, p. 4). From the authors’ perspective, the main reason for this is that the concept has been ‘plagued by misleading dichotomies’ (p. 11). Interpretations of the definition of competence as ‘complex ability constructs that are context-specific […], and closely related to real life’ (Koeppen et al. 2008, p. 61) tend to focus either on the performance or the disposition aspect which leads to a dichotomy: is behaviour the focus of competence or is it the criterion against which dispositions are validated as measures of competence? Both approaches have their advantages and disadvantages. The first position describes a holistic perspective in which dispositions and performance are complexly linked and may change during the course of performance. In this understanding, it is of specific importance how precisely the different dispositions are linked and what influences their interaction. The second position takes a more analytical stance by dividing competence into multiple constituents. The major question is whether competence can be exhaustively decomposed into identifiable constituents. Sadler (2013) argues that while decomposition reduces complexity and provides highly visible learning goals, it becomes more difficult to see the whole. Moreover, decomposition can lend itself to seriously deficient implementation. Teachers might become encouraged to deliberately coach students over the pass lines for specific competences – however, this ‘does not necessarily translate into a coordinated ability to complete a complex task with proficiency’ (p. 17). According to Blömeke et al. (2015) this dichotomised discussion neglects the processes that connect dispositions and performance. They argue for regarding competence as a process, a continuum ‘from traits that underlie perception, interpretation, and decision-making skills, which in turn give rise to observed behaviour in real-world situations’ (p. 3).

Based on the prominence given to the concept of competence in international comparisons of educational outcomes and national standards, the assessment of competences has become a major focus in educational research. The valid assessment of competences is regarded as essential for the enhancement of educational processes and the development of educational systems. Assessments developed to measure competences have to meet specific requirements that differ from traditional knowledge tests. It has to be insured, for example, that the sampling of real-life situations is representative of the universe of tasks (Blömeke et al. 2015). The dichotomy between holistic and analytical views of competence, however, is also reflected in the assessment of competences (Blömeke et al. 2015).

The analytic view of competence assessment focuses on measuring different latent traits (cognitive, conative, affective and motivational) with different instruments (Blömeke et al. 2015). This requires the development of sophisticated models of the structure and levels of these constructs that precisely define them in specific domains. According to Klieme et al. (2008), the development of cognitive competence models faces two major challenges. The first challenge is related to the contextualised character of competences which means that individual- and situation-specific components have to be simultaneously considered. This leads to the distinction between two types of theoretical models to describe competences that are ideally complementary: models of competence levels, defining the specific situational demands that can be mastered by individuals with certain levels of competences, and models of competence structures – dealing with the relations between performances in different contexts and seeking to identify common underlying dimensions. The second challenge is related to the question of how competences develop. Only few models have addressed this developmental aspect and their conceptualisations differ. Whereas some models regard competence development as a continuous progression from the lowest to the highest competence level, others conceptualise it as a noncontinuous process characterised by qualitative leaps. Related to the question of how competences develop is the question of to what extent such developmental models can represent cognitive processes (Leuders and Sodian 2013). Once theoretical competence models have been developed, they need to be linked to the results of empirical assessment by psychometric models. Here again the contextualised and complex nature of the competence construct defines certain requirements. The models need to incorporate all relevant characteristics of the individuals whose competences are to be evaluated while at the same time they have to take domain-specific situational demands into account. The holistic perspective on competence assessment focuses instead on assessing real-life performance without accounting for the contribution of specific dispositional resources (e.g. Shavelson 2010). However, this approach also has specific challenges. Performance tasks are often time-consuming and introduce considerable amounts of measurement error due to their complexity. Nevertheless, recent examples show that the approach is not impossible (e.g. Theyßen et al. 2014). Especially in large-scale assessments, simulation-based test instruments have been shown to provide potential in this context (OECD 2016; Theyßen et al. 2016).

In their review, Blömecke and colleagues (2015) argue that moving the field forward is not a question of choice between the analytical or holistic approaches but rather of finding ways to productively combine them (cf. Grugeon-Allys et al. 2016), thus moving ‘beyond dichotomies’ (p. 9). As stated above, in educational practice and research, competences usually relate to specific content areas (Koeppen et al. 2008), so-called domains. Typical domain-specific competences in primary and secondary education include scientific competence, technological competence and mathematical competence. These domain-specific competences are described in the next three sections. In addition, transversal competences often referred to as key competences are becoming more and more important for the participation of individuals in society and in the workplace. This development is picked up in the fourth section on innovation competence.

Competences in Science Education

In science education many educational standards and curricula are based on the concept of competence or related to it. The educational standards in many countries define specific competences as learning outcomes at a certain educational level (e.g. National Research Council 2012; Qualifications and Curriculum Authority 2007). However, the exact definition of these learning outcomes might differ from country to country (cf. Waddington et al. 2007).

From the perspective of science education, competent students have to solve specific types of problems and have to deal with certain kinds of concrete situations relevant for science. More specifically, students have to detach science-specific cognitive skills and knowledge from one situation and apply it to scientific problems in another situation, e.g. a social setting (Kauertz et al., 2012). A typical classroom situation where students are faced with scientific phenomena and problems that are explored or investigated through inquiry is described in the following box.

Starting question given by the teacher:

Usually when I am taking my effervescent Vitamin C drink I wait until it [has] stopped fizzing before I drink it. Some mornings I am running late for school. Can I speed up this reaction?

Equipment students receive:

Vitamin C effervescent tablets, boiling tubes, test tubes, 250 ml beakers, 100 ml measuring cylinders, stop watches, […].

Problems students have to solve:

1. Which variable should be changed?
2. How to measure the effect of the change?

(Black and Harrisson 2016, p. 25; see also http://results.sails-project.eu/units/reaction-rates).

A more general understanding of being competent in science was described by the OECD in the context of international large-scale studies in terms of scientific literacy. Within PISA, scientific literacy is defined as ‘the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen. A scientifically literate person is willing to engage in reasoned discourse about science and technology which requires the competencies to: 1. Explain phenomena scientifically […], (2) Evaluate and design scientific enquiry […], and (3) Interpret data and evidence scientifically’ (OECD 2016, p. 20).

Students need to apply these competences in different situations reflecting personal, local, national and global contexts which in turn require them to draw on their scientific knowledge and apply it in the context of life situations (OECD 2016).

Relating this back to science teaching and learning, effective learning strategies should include 'using a wide range of contexts, inductive rather than deductive processes, problem-based learning contexts in which problems are integrated rather than broken into discrete, artificial elements, and encouragement of self-directed learning and self-reflection on learning styles' (Rychen and Salganik 2003, p. 58).

Although some disagreement with respect to the definition of scientific literacy has been found (Bybee 1997; DeBoer 2000; Roberts 2007), the different definitions show some common ground, namely, 'that scientific literacy usually implied a broad and functional understanding of science for general education purposes and not preparation for specific scientific and technical careers' (DeBoer 2000, p. 594). In this sense, scientific literacy is closely related to science for *all* and can be seen as a precondition for participating in a society that is shaped by science and technology (DeBoer 2000). The objective of these two concepts is the constitution of 'a common core of learning in science for all young people, regardless of their social circumstances and career aspirations' (American Association for the Advancement of Science 1989, 1990).

But, what are these types of problems and concrete situations that students face in science education? To answer this question one has to look at teaching and learning situations as well as at assessment situations. For both types of situations, examples have been published. For an overview, it is worthwhile to have a look at the PISA framework that defines relevant contexts for its assessment items: 'health and disease, natural resources, environmental quality, hazards, and the frontiers of science and technology' (OECD 2016, p. 24). These contexts can also serve as a frame for teaching and learning in school (Gilbert 2006). Science subjects like chemistry have to emphasise the relevance of the taught content and make this relevance explicit to the students (Bulte et al. 2006). It is assumed that this might help students understand the contribution of science to their future lives. The approach of contextualising teaching and learning has been picked up by several EU-funded development and research projects like ASSIST-ME (assistme.ku.dk/practical-examples/swiss-examples/), Establish (www.establish-fp7.eu), and mascil (www.mascil-project.eu).

Within the ASSIST-ME project, the different partners were asked in a nonrepresentative survey to define the concept of competence from the perspective of their respective countries. From the answers it becomes obvious that in all countries competences are seen as something each individual possesses and that have to be applied to specific situations in order to solve problems. Prerequisites for being competent in a specific domain are cognitive constructs like knowledge and skills as well as affective constructs like interest or motivation. In the following, some key quotations from the survey are shown in order to reflect the understanding of competence in some of the countries:

- 'The ability to perform a task that requires knowledge and skills is an outcome of a competence'. (Cyprus)
- 'Competence is such a development of person's knowledge, skills, attitudes, values and self-regulation in particular domain (e.g. problem solving, modelling, argumentation, empirical investigation), that make the person able to cope with

relevant challenges and demands, effectively solve the tasks, and creatively adjust oneself to domain relevant situations either in individual or the social perspective'. (Czech Republic)

- 'A person is scientifically competent when she/he has the ability and commitment to act, alone and together with others, in a way that takes advantage of scientific curiosity, knowledge, skills, strategies and meta-knowledge to create meaning and autonomy and exert codetermination in relevant life contexts'. (Denmark)
- 'In the national standards [of Switzerland] a competence includes both a skill (German: Handlungsaspekt, French: aspects de compétences) and a content (German: Themenbereiche, French: domaines thématiques). That is, a competence is determined by both a skill and a content'. (Switzerland)
- 'It can be defined as a combination of basic knowledge relevant to live in our society, capacities to involve them in diverse situations but also lifelong necessary attitudes as to be open to others, the appetite for search for truth, the respect of oneself and others, the curiosity and the creativity'. (France)

Competences in science education are manifold and often no concurrent or well-accepted definition of competences exists (cf. Rönnebeck et al. 2016). That's why the issue of measuring competences is still one of the driving questions of research and practice in science education (e.g. Gitomer and Duschl 1998; Harlen 2013). There is an ongoing debate on the validity of standardised and teachers' assessments (e.g. Black et al., 2010), the influence of assessment practices on daily teaching (Binkley et al. 2012; Cizek 2001) and the advantages and disadvantages of specific item formats (e.g. Haladyna et al. 2002). In view of the assessment of scientific competences, especially validity is of high importance: does the test measure the competence, e.g. planning an investigation that it aims to measure? Here it becomes obvious why a precise definition of the assessed construct is a prerequisite for each assessment. It is much easier to develop a test that is valid with regard to the competence of interest if a precise definition exists and if the behaviour students should show when planning an investigation is well defined.

Competences in Technology Education

The discussion in the introduction to this chapter on the relationship between the terms *literacy*, *Bildung* and *competence* is an interesting one in the context of technology education as it resonates with debates within technology education where the linguistic concepts and their definitions are not universally shared or understood. Different definitions of terminology across national contexts mean that there is no universal agreement about the terms or their use within technology education curricula. To further complicate matters, a fourth term is also in common use, that of *capability*. To understand the different perspectives, it is useful to start with the debate between the terms literacy and capability, as these provide two distinct approaches.

Technological literacy has been at the core of developments in technology education in many parts of the world, arguably spearheaded by the International Technology and Engineering Association (International Technology Education Association 2007). Technological literacy is defined as:

> … the ability to use, manage, assess and understand technology. A technologically literate person understands, in increasingly sophisticated ways that evolve over time, what technology is, how it is created and how it shapes society, and in turn is shaped by society. [...] A technologically literate person will be comfortable with and objective about technology, neither scared of it nor infatuated with it. (International Technology Education Association 2007, pp. 9–10)

An alternative position critiques the literacy definition as denying the importance of action: a capability perspective. Led by UK developments that argue for the need to develop agency through taking action, capability is about creating intentional change and improvement, through intervention in response to a need, want or opportunity. This concept has been at the core of the English National Curriculum for Design and Technology since its creation in 1990, the essence of which is captured in the following extracts from a national curriculum statement:

> Design and technology prepares pupils to participate in tomorrow's rapidly changing technologies. They learn to think and intervene creatively to improve quality of life. The subject calls for pupils to become autonomous and creative problem solvers, as individuals and members of a team. [...] Through design and technology, all pupils can become discriminating and informed users of products, and become innovators. (Departmentment for Education and Employment/Qualifications and Curriculum Authority 1999, p. 15)

Critical terms here are *intervene* and *become innovators*. Capability is an active, rather than passive mode, having resonance with Sen's (1992) capabilities perspective that focuses on how a person functions – their beliefs and their actions. Critical in this is a sense of agency and, from a technology education perspective, capability that is manifest in a learner who can see a technological challenge that needs addressing and who has the confidence and competence to successfully intervene to create improvement.

The definition of competence, as outlined at the beginning of this chapter, relates to literacy as well as capability perspectives as both place strong emphasis on the procedural aspects of technology education: the processes of designing. But the term competence is not routinely applied across different national contexts. The increased global emphasis on core or key competences and their link to twenty-first-century skills has been of mixed value for technology education. As something that has been seen as important for high-stakes assessment in core subjects, there is evidence that technology education, not being seen as a core subject, is hence deprioritised in the curriculum (International Technology Education Association 2007). There are indications that implementing key competences has allowed technology education to be identified with more industry-focused competences such as problem-solving, rather than recognising its broader contribution to more generic competences (Ritz and Reed 2006; Williams 2006). Some national curricula have identified competences as ways of assessing standards and levels of attainment and have done this consistently, New Zealand's technology education curriculum being an example of this. Some curricula have used the term in the past but have then dropped it, for example, Sweden, where competences were highlighted in 2000 but are not mentioned in 2010, *ability* having taken their place (Skolverket 2009, 2012). But many national curricula for technology education make no mention of competences at all.

In the spirit of the key features of competence outlined in the introduction to this chapter, the consistent aspect of technology education that relates to competence is found in the procedural nature of the curriculum. There is a common pattern to the ways that technology education programmes are structured in different national contexts through three dimensions: the knowledge and skills base, the societal context and the processes of designing that enable technological developments. The essence of the subject lies in the ways in which these three dimensions interact and interplay through a common learning and teaching approach of project-based learning. Historically, the major focus in the forerunners of technology education was the development of craft skills, but a major change occurred in the late 1960s/early 1970s with a shift in focus from curriculum content to process. The shift occurred through innovations in assessment as early models of design processes were introduced as assessment criteria (Kimbell 1997). The initial developments were in the UK, but the approach has spread incrementally across the globe, and now having processes of designing at the core of learning, teaching and assessment is ubiquitous, and these processes lie at the heart of competence in technology education. However, competence does not reside in process alone; competence is developed and evidenced in the ways in which processes draw on knowledge, skills and understandings and how these are used within societal contexts.

The context is an important dimension in technology education, where the context of a task, or project, relates to societal needs (Kimbell and Stables 2007; Stables 2013). Design and technology contexts are situations in which challenges are embedded and provide the background to the people, places and purposes at the heart of the challenge. Good design and technological challenges, from a learning and teaching perspective, are rich in issues, competing priorities and conflicting values. One aspect of competence, therefore, is shown in ways that learners engage with a context, for example, by researching the types of stakeholders involved and using their research as a resource for understanding the needs in their challenge and in evaluating their approaches to address these needs. Knowledge and skill are critical, not for their own sake, but for the ways in which they are drawn on, learnt and developed based on the needs in the task. Thus, another dimension of competence is evidenced through a learner being able to draw appropriately on his or her existing knowledge and skills, recognise what new knowledge and skills are needed and know how to acquire them. Layton (1993) referred to this as seeing knowledge as a quarry to be exploited, not a cathedral to be worshipped. But the reality is that the quarry itself is difficult to define. Some knowledge can be easily identified as core to technology education, such as the properties of materials. But if a learner is designing a learning aid, for example, for a child with cerebral palsy, then knowledge of cerebral palsy is needed. Basically, any knowledge can become technological knowledge if it is needed for the task in hand. In relation to the content of a technology curriculum, the subject has been called 'a restive, itinerant, non-discipline' (Kimbell and Perry 2001), something that can present significant challenges for teachers.

The interlacing of the societal context of technological activities, the processes of designing and the knowledge and skills base that underpins competence in technology education has resulted in an inevitable shift away from atomistic approaches to teaching and assessment. While the extent of this differs, curriculum descriptors that integrate these dimensions are evident across national curricula documentation, as illustrated in the following extracts:

> Students create designed solutions for each of the prescribed technologies contexts based on an evaluation of needs or opportunities. They develop criteria for success, including sustainability considerations, and use these to judge the suitability of their ideas and designed solutions and processes. They create and adapt design ideas, make considered decisions and communicate to different audiences using appropriate technical terms and a range of technologies and graphical representation techniques. Students apply project management skills to document and use project plans to manage production processes. They independently and safely produce effective designed solutions for the intended purpose. (Australian Curriculum, Assessment and Reporting Authority 2016, p. 2)
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> Students […] understand that all design and technological practice takes place within contexts which inform outcomes […] use different design strategies, such as collaboration, user-centred design and systems thinking, to generate initial ideas and avoid design fixation […] design and develop at least one prototype that responds to needs and/or wants and is fit for purpose, demonstrating functionality, aesthetics, marketability and consideration of innovation […] make informed and reasoned decisions, respond to feedback about their own prototypes (and existing products and systems) to identify the potential for further development and suggest how modifications could be made. (Department for Education 2015, p. 7)
>
> Students will: Critically analyse their own and others' outcomes and their determination of fitness for purpose in order to inform the development of ideas for feasible outcomes. Undertake a critical evaluation that is informed by ongoing experimentation and functional modelling, stakeholder feedback, trialling in the physical and social environments, and an understanding of the issue as it relates to the wider context. Use the information gained to select, justify, and develop an outcome. Evaluate this outcome's fitness for purpose against the brief. Justify the evaluation using feedback from stakeholders and demonstrating a critical understanding of the issue that takes account of all contextual dimensions. (Ministry of Education 2010, p. 77)

Supporting learners to achieve competence in technology education is complex. Research has created understandings of a range of issues and opportunities to support learning, teaching and assessment of procedural competence, including importance of iterative approaches to design processes (Kimbell et al. 1991; Kimbell and Stables 2007), approaches to assessment for learning (McLaren 2012; Moreland et al. 2008; Moreland 2009), the impact of education paradigms (Mioduser 2015), maintaining authenticity in learning and assessment (Turnbull 2002; Snape and Fox-Turnbull 2013; Stables 2013), the use and challenges of assessment portfolios including e-portfolios (Doppelt 2009; Kimbell et al. 1991, 2009; Seery et al. 2012; Stables and Kimbell 2000; Williams 2013) and the use of judgement, holistic and comparative, in assessment (Kimbell et al. 1991; Kimbell 2012). Common to all the above research is a desire to provide insights and solutions to enable teachers to take on the significant challenges of teaching and learning to develop a breadth of procedural competences through technology education, some of which will be explained in the following chapter of the book.

Competences in Mathematics Education

In mathematics education, competence describes mastery of the cognitive requirements for successful performance in the content area of school mathematics: 'To master mathematics means to possess mathematical competence' (Niss 2004, p. 6). Kilpatrick (2014) describes the structuring of mathematical competence as frameworks which 'in mathematics education fall primarily into Weinert's specialized-cognitive-competencies category' (p. 85) in contrast to general cognitive competences, characterised by psychometric models of intelligence. The specialised nature of mathematics education is described as having potentially two components: specific mental processes sometimes coupled with collections of content over which these processes will be deployed. This is a characteristic of mathematics curriculum specifications. For example, the PISA study sets out a framework consisting of content categories (quantity, uncertainty and data, change and relationships, space and shape) together with process categories describing the problem-solving process and a set of seven 'fundamental mathematical capabilities' (OECD 2014, pp. 38–39). Basing new mathematics curricula on a notion of mathematical competence, the Danish KOM project set out two groups of competences describing 'the ability to ask and answer questions in and with mathematics' and 'the ability to deal with and manage mathematical language and tools' (Niss 2004, pp. 7–8).

A strongly associated idea is that of mathematical literacy, a term originally coined in the USA and used to underpin international large-scale assessments like TIMSS and PISA. Niss and Jablonka (2014) contrast mathematical literacy 'as a tool for solving nonmathematical problems' with mathematical competence being 'what it means to master mathematics at large, including the capacity to solve mathematical as well as nonmathematical problems' (p. 392). Here, nonmathematical problems describe those which are resolved from outside of mathematics, but could contain mathematical techniques in their solution. The distinction rests on a contrast between mathematical and nonmathematical problems, which is often problematic. In the PISA 2012 report, an example question is given in which Chris needs to choose between four cars with engine capacities (in litres) given as 1.79, 1.796, 1.82 and 1.783. Only one part deals with the engine capacities, being question 2, which asks: 'Which car's engine capacity is the smallest?' (OECD 2014, p. 42). It would be hard to see why knowing the smallest capacity of four engines of roughly 1.8 litres would be a component in the choice of a car. So, a reasonable conclusion would be that this is a purely mathematical problem placed in a story context.

Jablonka (2015) suggests that the teaching of 'more immediately useful mathematics [...] has been interpreted as a reaction to curriculum reforms associated with the 'new mathematics' [from the 1960s]' (p. 601), which being based on the formal mathematics of Bourbaki was a highly specialised presentation, 'aimed at identifying an essence of academic mathematics meant to be made accessible to all students' (p. 601). However, exercise problems were frequently placed in contexts exactly as in the PISA example above. This again suggests that the PISA question is an example of a purely mathematical problem.

The PISA question constructs action within school mathematics, being used as describing action in a process of car buying. The recognition rules for competence in car buying relate to a successful purchase, while within school mathematics a successful engagement with the mathematical ideas to be learned would be required. In school mathematics, we order decimals to demonstrate competence in the place value number system, whereas when buying a car we would consider all engines of roughly 1.8 litres as equivalent and look for other buying criteria. There has been a recontextualisation, and a mythological car buying practice has been constructed in its recruitment as a context within school mathematics. This is not in any sense real car buying, so the context of the car purchase and the engine sizes is a myth. Dowling (2010) refers to this as a push strategy in which the mathematical practice is pushed into the car buying practice and is privileged in doing so; it is the mathematical practical which gives purpose to this activity. He contends that 'school mathematics fails to provide transferrable competences in push mode' and the mathematical calculation provides no meaningful input to car buying. In contrast, in fetch mode, the mathematical practice is fetched from the car buying practice. So, the problem originating context is privileged and retains its recognition rules for competence within the problem-solving activity. However, 'it is an empirical question as to whether mathematical competences may be productively useable in fetch mode' (Dowling 2010, p. 5). Here, fetch mode gives rise to applied mathematics as one may expect it to be manifested in a professional setting, such as engineering, bridge building or medicine, where building a successful bridge or designing an effective drug are the privileged recognition rules. However, this is only very rarely seen in an educational setting. Mellin-Olsen's (1987) description of the multi-faceted, rich mathematical project he worked on with his students to inform parents about the issues associated with the extension of the nearby Bergen airport was certainly in fetch mode. However, a student, while happily engaged, is concerned that 'the other class is half-way through the book by now' (Mellin-Olsen 1987, p. 41). Fetch mode is hard to deploy in a crowded, exam-focused curriculum.

In school mathematics, inquiry is possible with problems set in purely mathematical contexts requiring an open, exploratory problem-solving approach. These are referred to as investigations in the UK. Here, there is no recontextualisation, the problem is solved entirely within the mathematical practice and hence the competences required are only mathematical. In contrast, open problems placed in a naturalistic setting but set within school mathematics are examples requiring mathematical modelling (Blum et al. 2007). Modelling generates an uncertain relationship between the problem-to-be-solved and the mathematical model.

Mathematical modelling is presented as a cyclical practice of action, critique and improvement between the originating practice (e.g. science or engineering) and the mathematical practice (Blum et al. 2007). In push mode, the originating practice is mythologised and the competences will be entirely mathematical. However, mathematical modelling provides the possibility for fetch mode, and in this case competences in both practices will be required.

We have described three types for inquiry-based learning: open problems solved within mathematics (investigation), open problems of application in push mode (which are purely mathematical questions set in context) and open problems in fetch mode (requiring mathematical modelling). The assessment implications of these three types are necessarily starkly different. Exercise questions set in context are a very standard feature of all public examinations in mathematics and, as we have seen, high-stakes international comparison tests. The answer is known and unambiguous and scored accordingly. In England, public examinations in mathematics were offered with up to 100% of the assessment allocated to 'coursework', teacher assessment, often including open tasks. Initially a very high level of freedom was accorded to teachers to decide what counted as coursework. However, the specification tightened considerably, and in its final incarnation an extended piece of open investigative work operating most commonly entirely within mathematics was graded according to three process strands (under the general heading of 'using and applying mathematics') with a multi-level statement bank offering performance descriptors under each strand. A formula then provided a score. However, by the later 1990s and 2000s, the difficulty of ensuring the security and reliability of independent teacher-assessed work in an era of greater government oversite leads to the abandonment of all coursework elements in high-stakes examinations. Mathematical modelling as described above has no heritage of assessment in high-stakes testing. However, the case study below describes an instance of an internal mechanism where such assessment could be developed.

In the recent EU-funded project ASSIST-ME (assistme.ku.dk/practical-examples/swiss-examples), students have engaged in inquiry-based problem-solving. For example, Swiss students in grades 4 and 6 worked on puzzle/game problems involving a board game with specified rules and end conditions. Students were invited to explore the game and describe the possible outcomes. Additionally, students in lower secondary level engaged with a problem of two cyclists who must share a bicycle to complete a journey, alternately walking and riding. In both cases a collection of assessed competences are given, one common to both activities being: 'exploring problems and making conjectures'. Competence here is demonstrated with mathematical recognition rules in the game case. The game is analysed purely as a mathematical practice. In the cycling case competence is recognised in push mode. Here, students must show competence in 'transferring problems into the 'mathematical world' (if necessary)'. The word *transferring* infers a modelling process, and indeed the problem potentially provides useful insights into the particular situation of sharing resources when walking and cycling. Competent conjecturing and exploration would need to be recognised in the cycling/walking setting as well as the mathematical realisation of it for the problem to operate in fetch mode and hence be an application. A range of assessment mechanisms are provided for in the materials: (1) on-the-fly teacher assessment of competence in the problem-solving process, (2) student-produced posters followed by classroom discussion of them, (3) written comment and peer feedback on student groups' oral presentations and (4) written comments and self-assessment of the competences which are given levels of achievement. All of these mechanisms operate within a framework described as assessment for learning (Black and Wiliam 2004; Hodgen and Wiliam 2006). The last item has the potential for an external assessment tool, but there is no suggestion that it could be used as such.

Mathematical competence is the successful deployment of capabilities in engagement with mathematical problems and with the language and tools of mathematics. It can be deployed in problem-solving within mathematics and from naturalistic settings. Competence is described as a collection of process categories sometime allied to content categories. However, mathematical engagement in naturalistic settings generates recontextualisations, frequently mythologising practices from outside of mathematics, as in the example of choosing a car on the basis of small differences in engine size. Problems in a mathematical setting can be used to directly develop and assess mathematical competences, whereas problems from nonmathematical settings require mathematical modelling in fetch mode to generate a credible application and hence a site where competence can be described.

Innovation Competence: A New Perspective

The present political context for education, in general, and science education, in particular, is permeated by the relatively new trend of seeing teaching as something that fosters students' innovation competence. This trend comes to the foreground in the twenty-first-century skills programme:

> Given the twenty-first century demands […] it should come as no surprise that creativity and innovation are very high on the list of twenty-first century skills. In fact, many believe that our current Knowledge Age is quickly giving way to an Innovation Age, where the ability to solve problems in new ways [will …] be highly prized. (Trilling and Fadel 2009, p. 56)

Indeed, key American, European and international policy organisations have called for changes to the educational systems that make future generations more innovative in order to secure sustained social welfare (European Commission 2010; OECD 2010; White House 2011). Clearly, the instalment of a buzzword such as *innovation* as a goal of teaching can frustrate science educators: exactly what do these new educational goals signify? Concrete understandings of innovation competence are still only emerging on the horizon. Unfortunately, the word innovation is often used in a way that connotes economical or financial gain, as a process that 'involves creating and marketing of the new' (Kline and Rosenberg 1986, p. 275). This pecuniary way of parsing innovation, however, seems ill-equipped as a learning goal for school science. A number of scholars have recently attempted to identify other ways of parsing *teaching-for-innovation* that are more suited to classroom teaching in the existing disciplines and which specify valuable skills and competences that cover various disciplines (e.g. Christensen et al. 2012; Nielsen 2015).

An important distinction should be made between entrepreneurship (understood here as the transformation of a service, product or process into financial gain) and innovation (which we could initially determine as the process of improving a field of practice by drawing on (inter-)disciplinary knowledge and skills (Nielsen and Holmegaard 2015; Rump et al. 2013). The focus here is on innovation, not on entrepreneurship.

In what seems to be the most detailed investigation yet of what innovation competence could be in a teaching context, Nielsen (2015) worked with groups of upper secondary school teachers from Denmark, who were experienced in designing teaching activities in their own disciplines that foster innovation. In Denmark, as well as in most other Nordic countries, innovation competence has been a focal point in educational policy for at least the last 20 years (see Danish Ministry of Education 1995; Nordic Council of Ministers 2011), but without a clear definition of what innovation competence is as a learning goal.

In the study of Nielsen (2015), from the teacher groups' talk about how to assess students' innovation competence in practice, there emerged a composite understanding of innovation competence that involves five dimensions: creativity, collaboration, (disciplinary) navigation, implementation and communication. For each dimension, Nielsen (2015) found key aspects in the teachers' talk that may be used as regulative ideals in assessing students along each dimension (for a more detailed outline of each dimension, see Nielsen 2015):

- Creativity involves students' ability to (1) independently find, or independently interpret a given problem issue from a field of practice, (2) generate a range of ideas or solutions to a problem rather than just one idiosyncratic type of idea and (3) to work with generated ideas in a critical fashion, e.g. by evaluating, sorting, revising and expanding the ideas of themselves or others. In this way the creativity dimension of innovation competence is in line with state-of-the-art notions of creativity in general, as an ability that involves both divergent (idea generating) and convergent (revising ideas in light of an end goal) processes (Cropley 2006). Further, this particular conception of creativity is in line with the more modern approach to creativity as a skill set that can be developed, rather than a stable trait of the individual (see, e.g. Jeffrey and Craft 2004).
- Collaboration involves students' ability to (1) take responsibility and facilitate that the collaborative group finishes its tasks, e.g. by being able to identify how the competences of the people in the group can complement each other, and (2) to include and be flexible in a collaboration, e.g. by being able to work with many different types of stakeholders or people, rather than just a limited number of people or classmates. This particular understanding of students' ability to collaborate resonates with recent attempts to formalise assessment of collaborative skills by OECD (2016) for PISA 2015.

- (Disciplinary) navigation involves students' ability to (1) interpret a specific problem from practice as a problem that can be approached from a disciplinary perspective, e.g. by being able to translate the problem into disciplinary language; (2) functionally handle knowledge, e.g. by handling a plentiful and heterogeneous information and sorting and prioritising which information is most important to go into detail with; and (3) master complex work process. Such aspects resonate well with recent attempts to formalise information literacy (Ainley et al. 2005; Binkley et al. 2012).
- Implementation (or action) involves students' ability to (1) make informed decisions about what actions to take in a set time in a work process, (2) take action outside their comfort zone (e.g. by seeking information outside the classroom) and (3) take risks and put themselves and others into play, e.g. by not stopping at the level of an idea, but carrying that idea out. As such, these aspects are in line with current trends in managerial education research (Oosterbeek et al. 2010), and they resemble what others have called implementation skills (e.g. The Conference Board of Canada 2013).
- Communication involves students' ability to (1) assess how to communicate (among themselves or to other stakeholders) in a given situation, (2) master a range of communication techniques and genres and (3) communicate in an engaging and convincing manner. Again, this set of aspects resonates with the communication aspects in the twenty-first-century skills programme (Binkley et al. 2012).

From such a perspective, innovation competence combines a multitude of sub-competences or skills that together could be determined as students' ability (alone or in collaboration with others) to (a) generate solutions to issues while drawing on their disciplinary knowledge and their analysis of the field of practice where the issue arises, (b) analyse and reflect on the value-creating potential and realisability of their ideas, (c) work towards implementing their ideas and (d) communicate about their ideas to various stakeholders (Nielsen and Holmegaard 2015). It should be noted that just like other generic competences (i.e. competences that are not endemic to one discipline alone) such as modelling or inquiry, there are aspects or dimensions of innovation competence that are also important in other competences.

Concluding Remarks

Summarising the development of the concept of competence in education in general as well as in the domains of science, technology and mathematics, it becomes obvious that the construct of competence is still difficult to define especially in relation to the concepts of Bildung and literacy. The conceptual delimitation stays rather vague. One reason is that competence is a complex construct relying on different constituents. An analytical perspective on competence thus naturally has limitations and is in danger of underrepresenting the construct. A more holistic perspective, on the other hand, better represents the construct.

In all three domains, science, technology and mathematics, curricula, standards, and assessment frameworks exist that define specific competences. These definitions can help to get a clearer picture of what competences are in distinct domains. These definitions also highlight that the concept of competence is similarly operationalised in these domains. However, in science and mathematics the concept of competence is still the subject of an ongoing debate that is not carried out in the same way in the field of technology. This might be due to the fact that the issues discussed, e.g. the role of contexts and the specificity of competencies in certain situations, are less controversial in technology because the essence of technology lies in the ways in which, e.g. societal contexts, students' knowledge and skills base and the processes of designing interact.

Furthermore, it also becomes obvious that the construct of competence in some respect goes beyond the concepts of Bildung and literacy. It is related much more to students' everyday life by focusing on complex problems that might be highly relevant to them. Although the focus on subject-specific contexts or everyday life situations is a similarity between the three domains, the nature of these contexts or situations differs because they reveal the intrinsic characteristic of each domain. In mathematics and also in science, the main objective of applying competences is to generate knowledge that is new to the students. This is why modelling is such an important competence in science education. In technology education the objective of applying competences is to develop a new product or to improve an existing one in order to meet societal or personal needs and expectations.

The concept of competence is seen as the answer to new developments and challenges in our society and world. Being competent means being able to address problems caused by these developments and challenges from a meta-perspective. Although it is a prerequisite, it is often not sufficient to be able to suggest and develop solutions for a specific problem. Students need to be able to generalise solutions or transfer them to different contexts; they need to realise when more information about a system or situation is needed or when potential risks need to be evaluated and traded versus potential benefits. Furthermore, they need to realise that no concrete solutions exist for some of the challenges facing humanity. Only then will they be able to react to our rapidly changing world and effectively participate in today's society and labour market. Here it becomes obvious that the concepts of knowledge and competences are intertwined. Reacting to problems in a competent way requires the application of existing knowledge. Otherwise, for example, it is not possible to interpret data to make evidence-based decisions.

New learning goals involve new teaching and learning approaches as well as new assessment methods. In view of teaching and learning approaches, it is important to develop students' competences by focusing on typical subject-specific thinking and working processes that help students solve problems in different situations (s. Chap. 2). In the classroom context, the authenticity of problems or situations often becomes inherently reduced. Even if some problems are highly relevant, they might be too complex for students to *solve* in a classroom situation. Therefore, teachers have to create learning situations that fit students' level of cognitive development and that are nevertheless as realistic as possible. Otherwise the gap between the classroom context and real-life situations might hinder meaningful learning and successful transfer of knowledge and competences. With respect to the assessment of competences, the complexity of the construct afflicts issues of validity and reliability. It is obviously not possible to measure the full range of students' competences in a valid and reliable way using only one test. Therefore, it is still a challenge to develop valid and reliable tests that cover different competences and that are useful for formative and summative assessment purposes (s. Chap. 3).

Altogether, defining, teaching and learning competences as well as the assessment of competences remain challenges for science, technology and mathematics education. One possibility to overcome the existing dichotomy between an analytical and a holistic view could be the more integrated framework proposed by Blömeke et al. (2015) that encompasses competences including indicators for cognitive, affective and motivational traits demanded in particular situations and related to the performance through a set of perceptual, interpretive and decision-making processes.

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